This report has been modified, but the changes are not reflected in the report below.

To view the EPA approved modification document, please return to the approved reports page located at https://www.deq.virginia.gov/TMDLDataSearch/ReportSearch.jspx and enter your query. In the results table, select “MODIFICATION” in the Final Reports column.

Fecal Bacteria and General Standard Total Maximum Daily Load Development for

Straight Creek

Submitted By:

MapTech, Inc.
1715 Pratt Drive, Suite 3200
Blacksburg, VA 24060
Phone: 540.961.7864, FAX 540.961.6392
http://www.maptech-inc.com/

Crop and Soil Environmental Sciences
Virginia Polytechnic Institute and State University

Prepared for:

Department of Mines, Minerals and Energy
and
Virginia Department of Environmental Quality

Draft Submitted: February 7, 2005
Revised Draft Submitted: July 7, 2005
Final Document Submitted: September 6, 2005
Re-Submitted: February 2006
Re-Submitted: March 29, 2006

This page intentionally left blank

CONTENTS

This page intentionally left blank

FIGURES

TABLES

ACKNOWLEDGEMENTS

Virginia Department of Mines, Minerals and Energy (DMME)
Division of Mined Land Reclamation (DMLR)

Virginia Department of Environmental Quality (VADEQ), Central Office
VADEQ, Southwest Regional Office

Virginia Department of Conservation and Recreation (VADCR)

Daniel Boone Soil and Water Conservation District (DBSWCD)

Natural Resources Conservation Service (NRCS)

Virginia Cooperative Extension Service (VCE)

Local Stakeholders and Watershed Residents

MapTech, Inc. of Blacksburg, Virginia, supported this study through the
Virginia Polytechnic Institute and State University
Department of Crop and Soil Environmental Sciences led by Dr. Charles Hagedorn,
through funding provided by the Virginia Department of Mines, Minerals and Energy
contract #C046066

This page intentionally left blank

EXECUTIVE SUMMARY

Background and Applicable Standards

The mainstem of Straight Creek was initially listed on the *Virginia 1994 TMDL Report* for violations of the bacteria standard and the *Virginia 1996 Section 303(d) TMDL Priority List* for violations of the General Standard (benthic). Elevated levels of fecal coliform bacteria recorded at VADEQ ambient water quality monitoring stations showed that this stream segment does not support the primary contact recreation use (*e.g.,* swimming, wading, and fishing). The modified RBP II method results rated Straight Creek as moderately impaired. The Virginia state standard (9 VAC 25-260-170) specifies that the number of fecal coliform bacteria shall not exceed a maximum allowable level of 400 colony-forming units (cfu) per 100 milliliters (mL). Alternatively, if data is available, the geometric mean of two or more observations taken in a calendar month should not exceed 200-cfu/100 mL. A review of available monitoring data for the watershed indicated that fecal coliform bacteria were consistently elevated above the 400-cfu/100 mL standard. Based on exceedances of the standards recorded at Virginia Department of Environmental Quality (VADEQ) monitoring stations, the stream does not support primary contact recreation (*e.g.,* swimming, wading, and fishing).

The United States Environmental Protection Agency (EPA) directed that the state develop a water quality standard for *E. coli* bacteria to eventually replace the fecal coliform standard. This new standard specifies that the number of *E. coli* bacteria shall not exceed a maximum allowable level of 235-cfu /100 mL (9 VAC 25-260-170). In addition, if data is available, the geometric mean of two or more observations taken in a calendar month should not exceed 126-cfu/100 mL.

The General Standard is implemented by VADEQ through application of the modified Rapid Bioassessment Protocol II (RBP II). Using the modified RBP II, the health of the benthic macro-invertebrate community is typically assessed through measurement of 8 biometrics that evaluate the overall health community. Each biometric measured at a target station is compared to the same biometric measured at a reference (not impaired) station to determine each biometric score. These scores are then summed and used to determine the overall bioassessment (*e.g.,* not impaired, slightly impaired, moderately impaired, or severely impaired). The modified RBP II method results rated Straight Creek as moderately impaired.

TMDL Endpoint and Water Quality Assessment

Fecal Coliform

Potential sources of fecal coliform include both point source and nonpoint source contributions. Nonpoint sources include: wildlife, grazing livestock, land application of manure, urban/suburban runoff, failed and malfunctioning septic systems, and uncontrolled discharges (*e.g.,* straight pipes). There is one Virginia Pollutant Discharge Elimination System (VPDES) permitted dischargers in the Straight Creek watershed which is not permitted for fecal control.

Fecal bacteria TMDLs in the Commonwealth of Virginia are developed using the *E. coli* standard. A translator developed by VADEQ was used to convert fecal coliform values to *E. coli* values. For the development of these TMDLs, the in-stream *E. coli* target was a geometric mean not exceeding 126-cfu/100 mL and a single sample maximum of 235-cfu/100 mL.

General Standard (benthic)

TMDLs must be developed for a specific pollutant(s). Benthic assessments are very good at determining if a particular stream segment is impaired or not, but generally do not provide enough information to determine the cause(s) of the impairment. The process outlined in the Stressor Identification Guidance Document (EPA, 2000) was used to systematically identify the most probable stressors in Straight Creek. Chemical and physical monitoring data from VADEQ and DMME monitoring point identification sites (MPIDs) provided evidence to support or eliminate potential stressors. The potential stressors are: sediment, toxics, low dissolved oxygen, nutrients, pH, metals, conductivity, temperature and organic matter.

The results of the stressor analysis for Straight Creek were divided into three categories:

Non-Stressor: Those stressors with data indicating normal conditions, without water quality standard violations or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors.

Possible Stressor: Those stressors with data indicating possible links, but inconclusive data, were considered to be possible stressors.

Most Probable Stressor: The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s).

The results indicate that for Straight Creek, sediment and total dissolved solids (TDS) are the Most Probable Stressors and, therefore, were used to develop the benthic TMDL.

Sediment is delivered to Straight Creek through surface runoff, streambank erosion, point sources, and natural erosive processes. During runoff events, sediment is transported to streams from land areas. Rainfall energy, soil cover, soil characteristics, topography, and land management affect the magnitude of sediment loading. Livestock concentrations (along stream edge and uncontrolled access to streams), forest harvesting, and construction accelerate erosion at varying degrees.

Sediment transport is a natural and continual process that is often accelerated by human activity. An increase in impervious land without appropriate stormwater control increases runoff volume and peaks, which leads to greater potential for channel erosion. During dry periods, sediment from air or traffic builds up on impervious areas and is transported to streams during runoff events. Fine sediments are included in total suspended solids (TSS) loads that are permitted for wastewater, industrial stormwater and construction stormwater discharge.

Sources contributing to the TDS impairment include both nonpoint contributions and point sources. Nonpoint sources in the Straight Creek watershed are abandoned mine land (AML) (*e.g.,* mine spoils, benches, and disturbed areas), urban areas, and land currently being mined. There are currently 50 permitted discharges in the Straight Creek watershed, one VPDES, and 49 sedimentation basin outlets.

Modeling Procedures

Hydrology

The US Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to model hydrology, TDS loads and fecal coliform loads.

For purposes of modeling watershed inputs to in-stream water quality, the Straight Creek watershed model consisted of four subwatersheds. The representative flow period used for hydrologic calibration was 10/1/1991 through 3/31/1995. The stream flow in the North Fork Powell River watershed including Straight Creek was calibrated with the flow values from USGS Station #03530500 in the North Fork Powell River at Pennington Gap.

Hydrology validation was not performed for Straight Creek because a stable time period was chosen for hydrology modeling and all observed data collected during this time period was used for hydrology calibration. It was determined that using all available data for calibration would result in a more accurate model.

Fecal Coliform

The fecal coliform water quality calibration for Straight Creek was conducted using monitored data collected at VADEQ monitoring station 6BSRA00.1.11 from October 1990 to September 1994. Modeled fecal coliform levels matched observed levels, indicating that the model was well calibrated.

The allocation precipitation time periods were selected to coincide with the calibration time periods. Modeling during the calibration periods provided the highest confidence in allocation results.

General Standard (benthic) - TDS

There are no existing in-stream criteria for TDS in Virginia; therefore, a reference watershed approach was used to define allowable TMDL loading rates in the Straight Creek watershed. The Middle Creek watershed was selected as the TMDL reference for

Straight Creek due its history of mining activity and recovery from a benthic impairment. The 90th percentile TDS concentration measured in Middle Creek was used as the endpoint for the TMDL (334 mg/L).

General Standard (benthic) - Sediment

There are no existing in-stream criteria for sediment in Virginia; therefore, a reference watershed approach was used to define allowable TMDL loading rates in the Straight Creek watershed. The Middle Creek watershed was selected as the TMDL reference for Straight Creek due to the history of coal mining in both watersheds. The TMDL sediment loads were defined as the modeled sediment load for existing conditions from the non-impaired Middle Creek watershed, area-adjusted to the Straight Creek watershed. The Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992) was used for comparative modeling between the impaired creek and Middle Creek.

Existing Conditions

Fecal Coliform

Wildlife populations, the rate of failure of septic systems, domestic pet populations, and numbers of livestock in the Straight Creek watershed are examples of land-based nonpoint sources used to calculate fecal coliform loads. Also, represented in the model were direct nonpoint sources of uncontrolled discharges, direct deposition by wildlife, and direct deposition by livestock. Contributions from all of these sources were updated to 2004 conditions to establish existing conditions for the watershed. The HSPF model provided a comparable match to the VADEQ monitoring data, with output from the model indicating violations of both the instantaneous and geometric mean standards throughout the watershed.

General Standard (benthic) - TDS

Both point and nonpoint sources of TDS were represented in the model during the hydrology and TDS calibration periods. Permitted sources included discharges of runoff through control structures (sediment retention ponds), as well as discharges from deep mines. Deep mine discharges were modeled by adding a time series of pollutant and flow inputs to the stream. Nonpoint sources were modeled as having three potential delivery pathways, delivery with TDS in surface runoff, delivery through interflow, and delivery through groundwater. The allocation precipitation time periods were selected to coincide with the calibration time periods. Modeling during the calibration periods provides the highest confidence in allocation results.

General Standard (benthic) - Sediment

The sediment TMDL for Straight Creek was defined by the average annual sediment load in metric tons per year (Mg/yr) from the area-adjusted Middle Creek. The sediment loads for existing conditions were calculated using the period of October 1991 through March 1995 for Straight Creek.

The sediment TMDL is composed of three components: waste load allocations (WLA) from point sources, the load allocation (LA) from nonpoint sources, and a margin of safety (MOS), which was set to 10% for this study. The existing load from Straight Creek was 7,225 Mg/yr. The target sediment TMDL load for Straight Creek is 5,518 Mg/yr.

Load Allocation Scenarios

Fecal Coliform

The next step in the bacteria TMDL process was to reduce the various source loads to levels that would result in attainment of the water quality standards. Because Virginia's *E. coli* standard does not permit any exceedances of the standard, modeling was conducted for a target value of 0% exceedance of the geometric mean standard and 0% exceedance of the single sample maximum *E. coli* standard. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality.

The recommended load allocation for Straight Creek includes the following reductions:

- 32% reductions in NPS wildlife loads,
- 80% reductions in NPS loads from pasture,
- 99% reductions in urban areas, and
- 100% reductions in loads from straight pipes.

Correcting all straight pipes results in a 2.19% violation of the instantaneous standard and is the Stage I implementation goal.

General Standard (benthic) – TDS

The next step in the TDS TMDL process was to adjust TDS loadings from existing watershed conditions to reduce the various source loads to levels that would result in an in-stream TDS concentration less than 334 mg/L. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Allocations were developed at the outlet of Straight Creek. The following is the recommended load allocation scenario for Straight Creek:

- 48% reduction in TDS from nonpoint sources, and
- 100% reduction in TDS from direct sources.

The only direct sources of TDS in Straight Creek are straight pipes. No TDS reductions from permitted sources are currently quantified. If reductions from permitted sources are required in the future, the reductions will be made through the application of appropriate BMPs.

General Standard (benthic) - Sediment

The next step in the sediment TMDL process was to reduce the various source loads to result in average annual sediment loads less than the target sediment TMDL load. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Allocations were developed at the outlet of Straight Creek.

The final load allocation scenario for Straight Creek recommended a 64.58% overall reduction in sediment loads to the stream. The overall reduction includes reductions of 65% from disturbed forest, 79% from AML, as well as 100% reduction from straight pipes (uncontrolled discharges). No reductions to sediment or TSS permitted sources were required.

Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria, TDS and sediment impairments of Straight Creek. The second step is the development of TMDL implementation plans. The final step is to implement the TMDL implementation plan, and to monitor water quality to determine if water quality standards are being attained.

Once EPA approves a TMDL, measures must be taken to reduce pollution levels in the stream. These measures, which can include the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. In general, Virginia intends for the recommended reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource.

To address the bacteria TMDL, reducing the human bacteria loading from straight pipes and failing septic systems should be a primary implementation focus because of the health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system installation/repair program. Livestock exclusion from streams has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the direct cattle deposits and by providing additional riparian buffers. Reduced trampling and soil shear on streambanks by livestock has been shown to reduce bank erosion.

To address the TDS and sediment TMDLs, It is anticipated that AML reclamation and the correction of straight pipes will be initial targets of implementation. One way to accelerate reclamation of AML is through remining. The Virginia Department of Mines, Minerals and Energy's (DMME) Division of Mined Land Reclamation (DMLR), The Nature Conservancy, Virginia Tech/Powell River Project, and U. S. Office of Surface Mining are in the process of developing incentives that will promote economically and environmentally beneficial remining operations that reclaim AML sites (DMME, 2004).

There is a measure of uncertainty associated with the final allocation development process. Monitoring performed upon completion of specific implementation milestones can provide insight into the effectiveness of implementation strategies, the need for amending the plan, and/or progress toward the eventual removal of the impairment from the 303(d) list. The primary purpose of the TMDL is restoration of the aquatic community and not attainment of TDS/TSS waste load allocations. Should the benthic community recover prior to reaching TDS and TSS target loads, VADEQ and DMME will propose to EPA and the State Water Control Board (SWCB) that these wasteload allocations be amended to reflect new information.

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use. In order for a stream to be assigned a new designated use, or a subcategory of a use, the current designated use must be removed. The state must also demonstrate that attaining the designated use is not feasible. Information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens as well as EPA will be able to provide comment during this process.

Public Participation

During development of the TMDLs for Straight Creek, public involvement was encouraged through three public meetings in the watershed. An introduction of the agencies involved, an overview of the TMDL process, and the specific approach to developing the Straight Creek TMDLs were presented at the first public meeting. Details of the pollutant sources and stressor identification were presented during the second public meeting. Public understanding of and involvement in the TMDL process was encouraged. Input from these meetings was utilized in the development of the TMDLs and improved confidence in the allocation scenarios. The final model simulations and the TMDL load allocations were presented during the final public meeting. There was an extended public comment period after the final public meetings and comments received from six organizations have been addressed. Watershed stakeholders will have the opportunity to participate in the development of the TMDL implementation plan.

1. INTRODUCTION

1.1 Background

The need for Total Maximum Daily Loads (TMDLs) for Straight Creek is based on provisions of the Clean Water Act. The United States Environmental Protection Agency's (EPA) document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA, 1999), states:

> *According to Section 303(d) of the Clean Water Act and the EPA water quality planning and management regulations, States are required to identify waters that do not meet or are not expected to meet water quality standards even after technology-based or other required controls are in place. The waterbodies are considered water quality-limited and require TMDLs.*
>
> *…A TMDL is a tool for implementing State water quality standards, and is based on the relationship between pollution sources and in-stream water quality conditions. The TMDL establishes the allowable loadings or other quantifiable parameters for a waterbody and thereby provides the basis for States to establish water quality-based controls. These controls should provide the pollution reduction necessary for a waterbody to meet water quality standards.*

The Powell River watershed (USGS Hydrologic Unit Code #06010206) includes portions of Virginia's Wise and Lee Counties. The Powell River flows through Virginia and Tennessee and joins Clinch River at the Norris Reservoir. Straight Creek (located in Lee County) is a tributary to the Powell River and is part of the Upper Tennessee River Basin. (Figures 1.1 and 1.2)

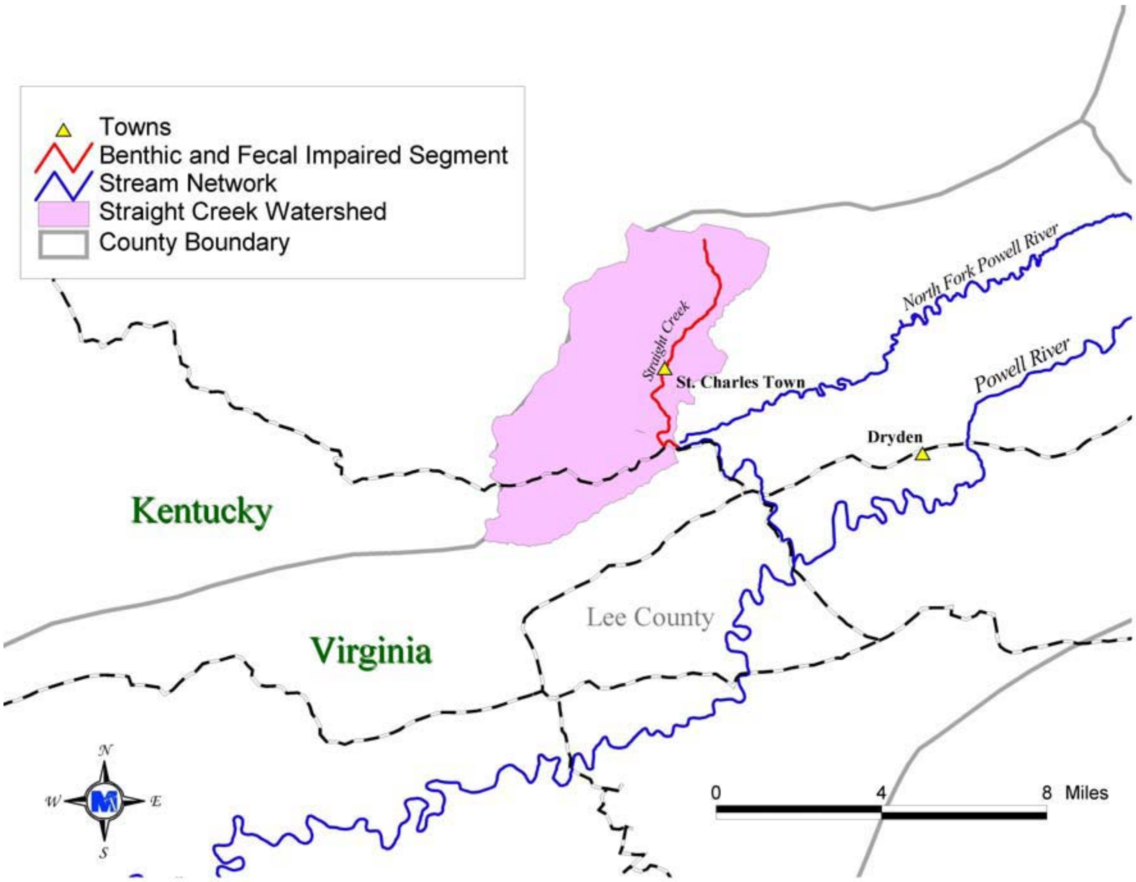

Figure 1.1 Location of the Straight Creek watershed.

Fecal violations at VADEQ ambient monitoring station 6BSRA001.11 on Straight Creek (waterbody ID #VAS-P20R) led to Straight Creek, from the headwaters north of Monarch to its confluence with North fork Powell River (6.66 miles), being placed on the 1994 *TMDL Report*. Straight Creek remained on the 1996 *Section 303(d) TMDL Priority List* for violations of the fecal coliform (FC) bacteria standard. In addition, Straight Creek, Stone Creek and tributaries (38.1 miles) were listed for violations of the General Standard (benthic) in 1996 based on monitoring at VADEQ biological station 6BSRA000.40.

These listings remained on the *Virginia 1998 Section 303(d) TMDL Priority List* for violations of the FC bacteria standard and the General Standard (benthic). The 6.66-mile segment of Straight Creek has remained on the Virginia 2002 and 2004 Section 303(d) lists for bacteria violations based on additional monitoring performed at VADEQ ambient station 6BSRA001.11. While the 1996 and 1998 Section 303(d) lists included a broad description of Straight Creek, Stone Creek and tributaries, in the 2002 and 2004 Section 303(d) lists the individual impairments were specifically defined. The 6.66-mile segment of Straight Creek remained on the *Virginia 1998 Section 303(d) TMDL Priority List* for not supporting aquatic life based on monitoring at VADEQ biological stations 6BSRA000.11, 6BSRA000.40, 6BSRA000.54, 6BSRA001.10, 6BSRA002.48, and 6BSRA003.62. As contracted by DMME, this TMDL was developed for Straight Creek from its headwaters to the confluence with the North Fork Powell River as listed in 2002. However, all load allocations identified in subsequent chapters reflect reductions required in all contributing subwatersheds.

This page intentionally left blank

PART II: FECAL BACTERIA TMDLS

This page intentionally left blank

2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Applicable Water Quality Standards

According to 9 VAC 25-260-5 of Virginia's State Water Control Board *Water Quality Standards*, the term "water quality standards" means "…provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law and the federal Clean Water Act."

As stated in Virginia state law 9 VAC 25-260-10 (Designation of uses):

> *A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.*
>
> ♦
>
> *D. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*

Because this study addresses both fecal bacteria and benthic impairments, two water quality criteria are applicable. Section 9 VAC 25-260-170 applies to the fecal coliform impairment, whereas the General Standard section (9 VAC 25-260-20) applies to the benthic impairment.

2.2 Applicable Criteria for Fecal Bacteria Impairments

Prior to 2002, Virginia Water Quality Standards specified the following criteria for a non-shellfish supporting waterbody to be in compliance with Virginia's fecal standard for contact recreational use:

> *A. General requirements. In all surface waters, except shellfish waters and certain waters addressed in subsection B of this section, the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria*

> *per 100 mL of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 mL at any time.*

If the waterbody exceeded either criterion more than 10% of the time, the waterbody was classified as impaired and the development and implementation of a TMDL was indicated in order to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion was applied to a particular datum or data set. If the sampling frequency was one sample or less per 30 days, the instantaneous criterion was applied; for a higher sampling frequency, the geometric criterion was applied. These were the criteria used for listing the impairment included in this study. Sufficient fecal coliform bacteria standard violations were recorded at VADEQ water quality monitoring stations to indicate that the recreational use designations are not being supported.

The EPA has since recommended that all states adopt an *E. coli* or *enterococci* standard for fresh water and *enterococci* criteria for marine waters by 2003. The EPA is pursuing the states' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and *enterococci*) and the incidence of gastrointestinal illness than with fecal coliform. *E. coli* and *enterococci* are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. The adoption of the *E. coli* and *enterococci* standard is in effect in Virginia as of January 15, 2003.

The new criteria, outlined in 9 VAC 25-260-170, read as follows:

> *A. In surface waters, except shellfish waters and certain waters identified in subsection B of this section, the following criteria shall apply to protect primary contact recreational uses:*
>
> *1. Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 mL of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.*

2. E. coli and enterococci *bacteria per 100 mL of water shall not exceed the following:*

	Geometric Mean[1]	*Single Sample Maximum*[2]
Freshwater[3]		
E. coli	*126*	*235*
Saltwater and Transition Zone[3]		
Enterococci	*35*	*104*

[1] For two or more samples taken during any calendar month.

[2] No single sample maximum for *enterococci* and *E. coli* shall exceed a 75% upper one-sided confidence limit based on a site-specific log standard deviation. If site data are insufficient to establish a site-specific log standard deviation, then 0.4 shall be used as the log standard deviation in freshwater and 0.7 shall be as the log standard deviation in saltwater and transition zone. Values shown are based on a log standard deviation of 0.4 in freshwater and 0.7 in saltwater.

[3] See 9 VAC 25-260-140 C for freshwater and transition zone delineation.

These criteria were used in developing the bacteria TMDL included in this study.

2.3 Selection of a TMDL Endpoint.

The first step in developing a TMDL is the establishment of in-stream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. For the Straight Creek TMDL, the applicable endpoints and associated target values can be determined directly from the Virginia water quality regulations (Section 2.1). In order to remove a water body from a state's list of impaired waters, the Clean Water Act requires compliance with that state's water quality standard. Since modeling provided simulated output of *E. coli* concentrations at 1-hour intervals assessment of TMDLs was made using both the geometric mean standard of 126 cfu/100 mL and the instantaneous standard of 235 cfu/100 mL. Therefore, the in-stream *E. coli* targets for these TMDLs were a monthly geometric mean not exceeding 126 cfu/100 mL and a single sample not exceeding 235 cfu/100 mL.

2.4 Selection of a TMDL Critical Condition.

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of Straight Creek is protected during times when it is most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and help in identifying the actions that may have to be undertaken to meet water quality standards. Fecal coliform sources within the Straight Creek watershed are attributed to both point and nonpoint sources. Critical conditions for waters impacted by land-based nonpoint sources generally occur during periods of wet weather and high surface runoff. In contrast, critical conditions for point source dominated systems generally occur during low flow and low dilution conditions. Point sources, in this context, also include nonpoint sources that are not precipitation driven (*e.g.,* direct fecal deposition to stream).

A graphical analysis of measured fecal coliform concentrations versus the level of flow at the time of measurement showed that there was no obvious critical flow level in Straight Creek (Figure 2.1). High concentrations were recorded in all flow regimes.

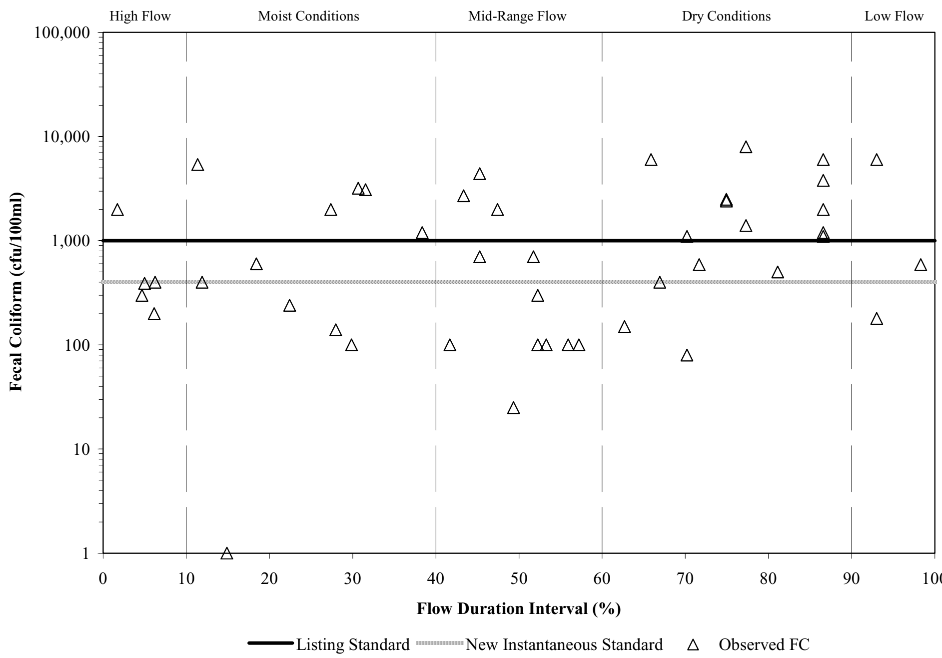

Figure 2.1 Relationship between fecal coliform concentrations in Straight Creek (VADEQ station 6BSRA001.11) and discharge at USGS Station #03400800.

2.5 Discussion of In-stream Water Quality

This section provides an inventory of available observed in-stream monitoring data throughout the Straight Creek watershed. An examination of data from water quality stations used in the Section 303(d) assessments and data collected during TMDL development were analyzed. Sources of data and pertinent results are discussed.

2.5.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information for Straight Creek are:

- bacteria enumerations from 4 VADEQ in-stream monitoring stations used for TMDL assessment (Figure 2.2, Tables 2.1 and 2.2), and
- bacterial source tracking from one VADEQ in-stream monitoring station analyzed during TMDL development.

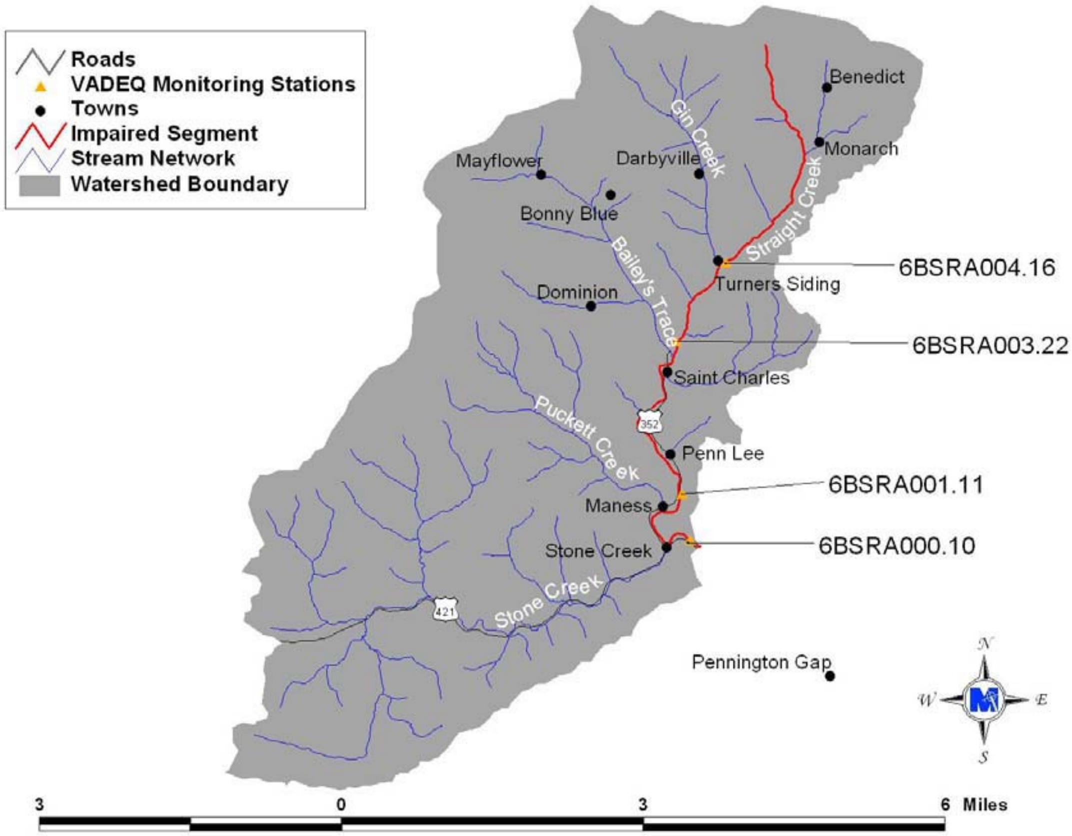

Figure 2.2 Location of VADEQ water quality monitoring stations used for the bacteria TMDL assessment in the Straight Creek watershed.

Table 2.1 Summary of fecal coliform monitoring conducted by VADEQ for Straight Creek from July 1990 through March 2004.

Stream	VADEQ Station	Count (#)	Minimum (cfu/100mL)	Maximum (cfu/100mL)	Mean (cfu/100mL)	Median (cfu/100mL)	Standard Deviation	Violations[1] %	Violations[2] %
Straight Creek	6BSRA001.11	47	0	8,000	1,595	600	1,984	45	57
Straight Creek	6BSRA003.22	9	130	1,800	809	820	526	22	78
Straight Creek	6BSRA004.16	9	150	2,000	1,137	1,300	678	67	78

[1] Violations are based on the pre-2003 fecal coliform instantaneous standard (1,000 cfu/100mL)
[2] Violations are based on the current fecal coliform instantaneous standard (400 cfu/100mL)

Table 2.2 Summary of *E. coli* monitoring conducted by VADEQ for Straight Creek from March 2000 through March 2004.

Stream	VADEQ Station	Count (#)	Minimum (cfu/100mL)	Maximum (cfu/100mL)	Mean (cfu/100mL)	Median (cfu/100mL)	Standard Deviation	Violations[1] %
Straight Creek	6BSRA000.10	4	25	2,000	600	188	941	50
Straight Creek	6BSRA001.11	7	20	800	381	140	393	43
Straight Creek	6BSRA003.22	9	50	1,800	651	780	556	67
Straight Creek	6BSRA004.16	9	50	800	511	650	301	78

[1] Violations are based on the new *E. coli* instantaneous standard (235 cfu/100mL)

2.5.1.1 Water Quality Monitoring for TMDL Assessment

Data from Straight Creek collected by VADEQ were analyzed from July 1990 through March 2004 and are shown in Tables 2.3 and 2.4. These tables summarize the bacteria samples collected at the in-stream monitoring stations used for TMDL assessment. Fecal coliform samples were taken for the express purpose of determining compliance with the state instantaneous standard limiting concentrations to less than 1,000 cfu/100 mL. Therefore, as a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100 mL or in excess of a specified cap (*e.g.*, 8,000 or 16,000 cfu/100 mL, depending on the laboratory procedures employed for the sample) were not analyzed further to determine the precise concentration of fecal coliform bacteria. The result is that reported concentrations of 100 cfu/100 mL most likely represent concentrations below 100 cfu/100 mL, and reported concentrations of 8,000 or 16,000 cfu/100 mL most likely represent concentrations in excess of these values. *E. coli* samples were collected to evaluate compliance with the state's current bacterial standard, as well as for bacterial source tracking analysis. The current instantaneous standard for *E. coli* is 235 cfu/100mL.

2.5.1.2 Water Quality Monitoring Conducted During TMDL Development

Ambient water quality monitoring was performed from July 2003 through June 2004. Specifically, water quality samples were taken at one site in the Straight Creek watershed (Figure 2.3). All samples were analyzed for fecal coliform and *E. coli* concentrations and for bacteria source (*i.e.,* human, livestock, pets, or wildlife) by the Environmental Diagnostics Laboratory (EDL) at MapTech, Inc. Table 2.3 summarizes the fecal coliform and *E. coli* concentration data at the ambient station. Bacterial source tracking (BST) is discussed in greater detail in Section 2.6.1.

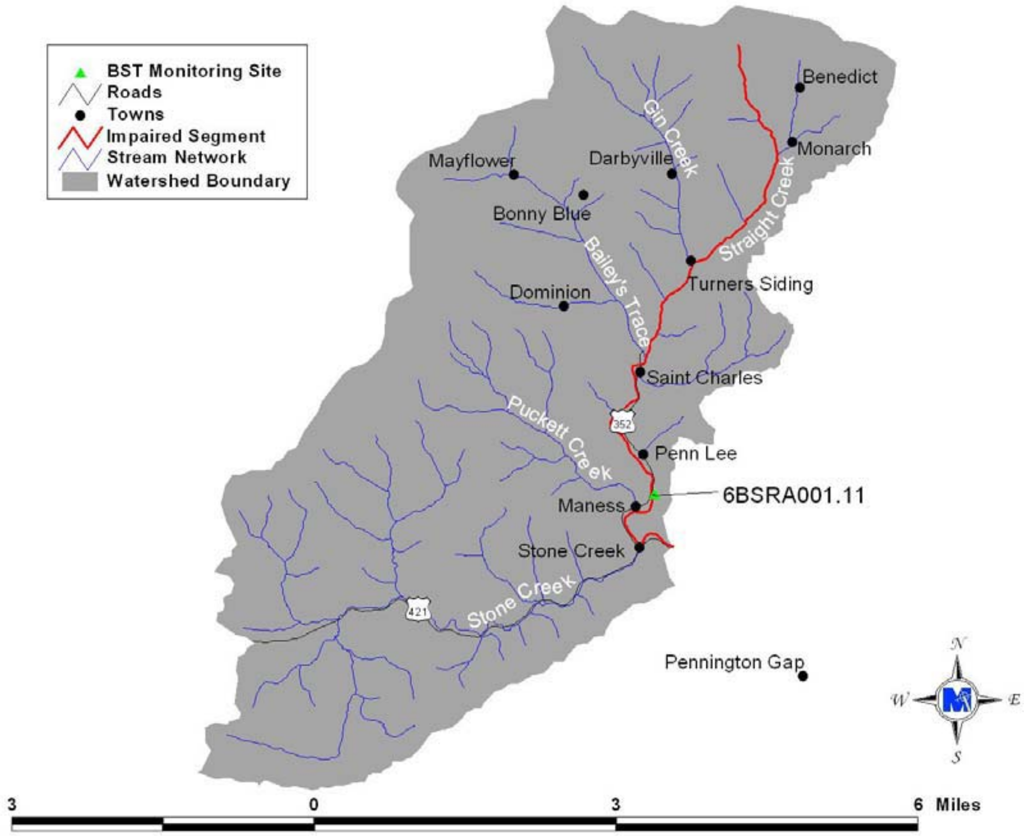

Figure 2.3 Location of the BST water quality monitoring station in the Straight Creek watershed.

2.6 Analysis of BST Data

The data collected were analyzed for frequency of violations, patterns in fecal source identification, and seasonal impacts. Results of the analyses are presented in the following sections.

2.6.1 Bacterial Source Tracking

MapTech, Inc. was contracted to perform analyses of fecal coliform and *E. coli* concentrations as well as bacterial source tracking. Bacterial source tracking is intended to aid in identifying sources (*i.e.,* human, pets, livestock, or wildlife) of fecal contamination in water bodies. Data collected provided insight into the likely sources of fecal contamination, aided in distributing fecal loads from different sources during model calibration, and will improve the chances for success in implementing solutions.

Several procedures are currently under study for use in BST. Virginia has adopted the Antibiotic Resistance Analysis (ARA) methodology implemented by MapTech's EDL. This method was selected because it has been demonstrated to be a reliable procedure for confirming the presence or absence of human, pet, livestock and wildlife sources in watersheds in Virginia. The BST results were reported as the percentage of isolates acquired from the sample identified as originating from humans, pets, livestock, or wildlife.

BST results of water samples collected at an ambient station in the Straight Creek watershed are reported in Table 2.3. The BST results indicate the presence of all sources (*i.e.,* human, wildlife, livestock, and pets) contributing to the fecal bacteria violations. The fecal coliform and *E. coli* enumerations are given to indicate the bacteria concentration at the time of sampling. The proportions reported are formatted to indicate statistical significance (*i.e.,* **BOLD** numbers indicate a statistically significant result), determined through two tests. The first was based on the sample size. A z-test was used to determine if the proportion was significantly different from zero (*alpha* = 0.10). Second, the rate of false positives was calculated for each source category in each library, and a proportion was not considered significantly different from zero unless it was greater than the false-positive rate plus three standard deviations.

Human was the most predominating sources of fecal bacteria, followed by wildlife. These results are consistent with local residents insight as to the sources of fecal contamination in these streams.

Table 2.4 summarizes the results for the station with load-weighted average proportions of bacteria originating from the four source categories. The load-weighted average considers the level of flow in the stream at the time of sampling, the concentration of *E. coli* measured, and the number of bacterial isolates analyzed in the BST analysis. Human is shown as the predominate source.

Table 2.3 Bacterial source tracking results from water samples collected in the Straight Creek impairment.

Station	Date	Fecal Coliform (cfu/100 mL)	*E. coli* (cfu/100 mL)	Percent Isolates classified as[1]: Wildlife	Human	Livestock	Pets
6BSRA001.11	7/21/03	3,300	260	**25%**	**37%**	**17%**	**21%**
	8/20/03	6,600	550	**25%**	**21%**	**37%**	**17%**
	9/17/03	350	300	**54%**	4%	**42%**	0%
	10/15/03	120	500	0%	8%	**84%**	8%
	11/17/03	580	142	**80%**	4%	8%	8%
	12/16/03	280	60	**21%**	**37%**	**17%**	**25%**
	1/12/04	60	96	**38%**	**50%**	8%	4%
	2/17/04	600	94	0%	**84%**	8%	8%
	3/17/04	170	76	**12%**	**80%**	0%	8%
	4/20/04	170	280	8%	**55%**	**33%**	4%
	5/12/04	120	20	**67%**	0%	0%	33%
	6/21/04	290	320	0%	**66%**	**17%**	**17%**

[1]**BOLD** type indicates a statistically significant value.

Table 2.4 Load weighted average proportions of fecal bacteria originating from wildlife, human, livestock, and pet sources.

Station ID	Stream	Wildlife	Human	Livestock	Pet
6BSRA001.11	Straight Creek	18%	44%	26%	11%

2.6.2 Trend and Seasonal Analyses

In order to improve TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on precipitation, fecal coliform concentrations, and water chemistry results. A Seasonal Kendall Test was used to examine long-term trends. The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the Seasonal Kendall Test can identify the trend (over many years) in discharge levels during a particular season or month.

A seasonal analysis of precipitation and fecal coliform concentrations was conducted using the Mood Median Test. This test was used to compare median values of precipitation, and fec Water quality monitoring data collected by VADEQ were described in Section 2.5. The Seasonal Kendall Test was conducted on fecal coliform concentrations collected at stations used in TMDL assessment if sufficient data were available. All stations showed no overall trends. All stations in the Straight Creek watershed showed no seasonality in fecal coliform concentrations.

al coliform concentrations in each month.

2.6.2.1 Fecal Coliform Concentrations

2.6.2.2 Precipitation

Daily precipitation measured at Pennington Gap, Virginia was used in analyses for Straight Creek. Total monthly precipitation measured in Pennington Gap, Virginia from January 1980 to March 2004 was analyzed, and no overall, long-term trend or seasonality (using the Moods Median Test) was found.

2.6.2.3 Summary of In-stream Water Quality Monitoring Data

A wide range of fecal coliform concentrations has been recorded in the watershed. Concentrations reported during TMDL development were within the range of historical values reported by VADEQ during TMDL assessment. Exceedances of the instantaneous standard were reported in all flow regimes, leaving no apparent relationship between flow and water quality.

3. SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential sources of fecal coliform in the Straight Creek watershed. The source assessment was used as the basis of model development and ultimate analysis of TMDL allocation options. In evaluation of the sources, loads were characterized by the best available information, landowner input, literature values, and local management agencies. This section documents the available information and interpretation for the analysis. The source assessment chapter is organized into point and non-point sections. The representation of the following sources in the model is discussed in Section 4.

3.1 Watershed Characterization

The National Land Cover Data (NLCD) produced cooperatively between USGS and the EPA was utilized for this study. The collaborative effort to produce this dataset is part of a Multi-Resolution Land Characteristics (MRLC) Consortium project led by four U.S. government agencies: EPA, USGS, the Department of the Interior National Biological Service (NBS), and the National Oceanic and Atmospheric Administration (NOAA). Using 30-meter resolution Landsat 5 Thematic Mapper (TM) satellite images taken between 1990 and 1994, digital land use coverage was developed identifying up to 21 possible land use types. Classification, interpretation, and verification of the land cover dataset involved several data sources (when available) including: aerial photography; soils data; population and housing density data; state or regional land cover data sets; USGS land use and land cover (LUDA) data; 3-arc-second Digital Terrain Elevation Data (DTED) and derived slope, aspect and shaded relief; and National Wetlands Inventory (NWI) data. Approximate acreages and land use proportions for the impaired watershed are given in Table 3.1.

Table 3.1 Current land use area for the Straight Creek watershed.

Land use	Straight Creek (acres)
AML	1,991
Barren	4.6
Commercial	17
Forest	14,142
Pasture/Hay	42
Permitted Mining	1,310
Residential	145
Row Crops	8.5
Water	6
Wetlands	3.2
Total	**17,670**

The majority of AML in the Straight Creek watershed is highwalls and their associated benches. The land area of the Straight Creek watershed is approximately 17,700 acres, with forest as the primary land use (Figure 3.1).

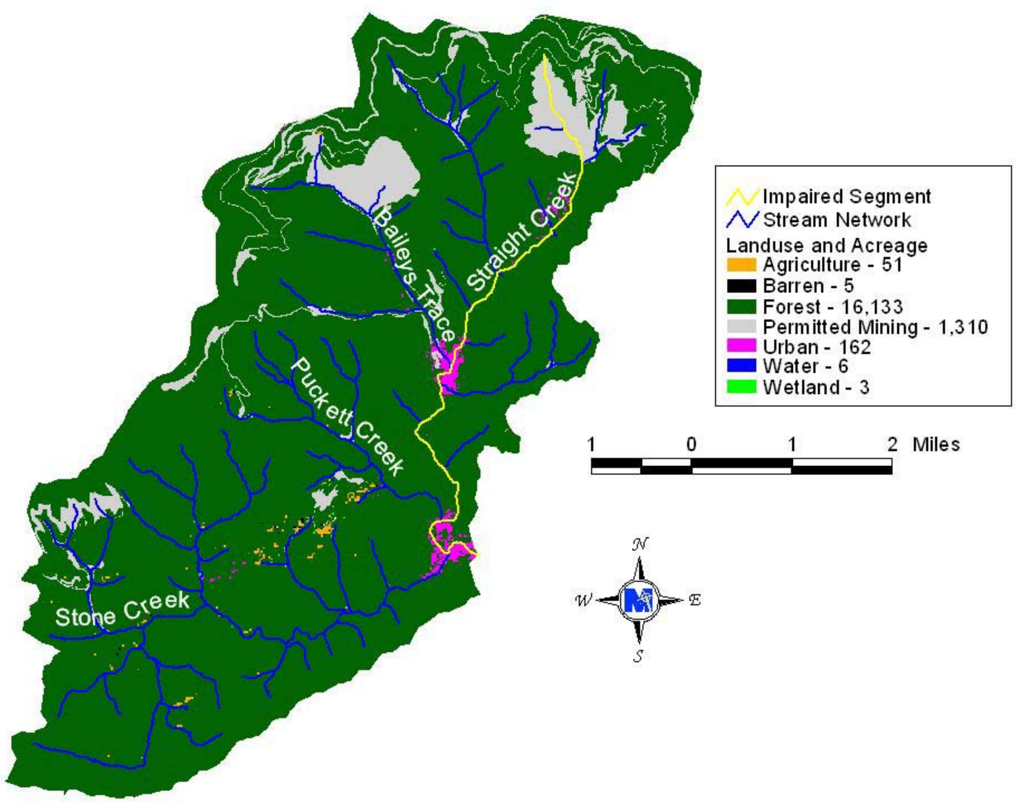

Figure 3.1 Land use in the Straight Creek watershed.

The estimated human population within the Straight Creek drainage area is 1,353 (USCB, 1990, 2000). Among Virginia counties, Lee County ranks 23rd for the number of all cattle and calves and 9th for beef cattle (Virginia Agricultural Statistics, 2001). Lee County is also home to 470 species of wildlife, including 55 types of mammals (*e.g.,* beaver, raccoon, and white - tailed deer) and 155 types of birds (*e.g.,* wood duck, wild turkey, Canada goose) (VDGIF, 2004).

For the period 1955 to 2004, the portion of the Powell River watershed near the town of Pennington Gap received average annual precipitation of approximately 49.48 inches, with 47% of the precipitation occurring during the May through October growing season (SERCC, 2004). Average annual snowfall is 17.5 inches with the highest snowfall occurring during January (SERCC, 2004). Average annual daily temperature is 54.6 ºF. The highest average daily temperature of 85.5 ºF occurs in July, while the lowest average daily temperature of 23.9 ºF occurs in January (SERCC, 2004).

3.2 Assessment of Point Sources

One non-mining point source is permitted in the Straight Creek watershed through the Virginia Pollutant Discharge Elimination System (VPDES). Figure 3.2 shows the permitted location. Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 mL. Currently, these permitted dischargers are expected not to exceed the 126 cfu/100mL *E. coli* standard. Table 3.2 summarizes data from this point source.

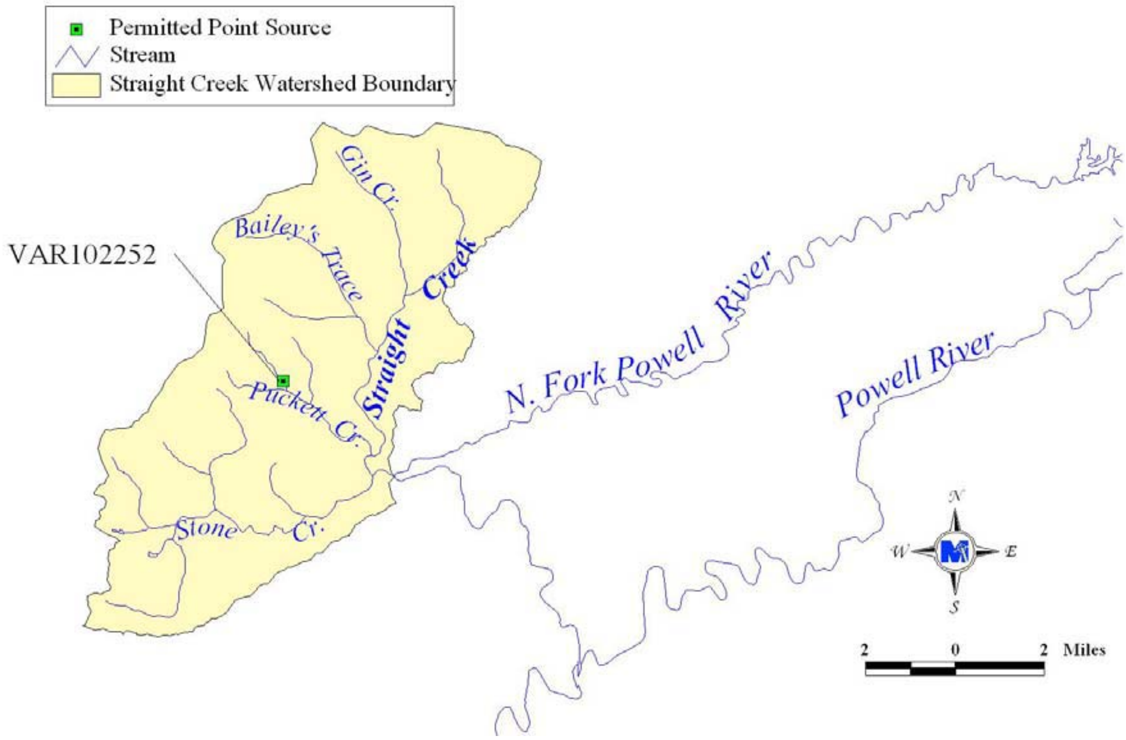

Figure 3.2 Location of VPDES permitted point sources in the Straight Creek watershed.

Table 3.2 Summary of VPDES permitted point sources in the Straight Creek watershed.

Facility Name	Permit No	Design Flow (MGD)	Permitted For Fecal Control	Data Availability	Receiving Stream
VDOT Jonesville - 0754 052 P59, N501	VAR102252	NA	No	ND	Puckett Creek

* ND – no data, facility not required to submit monitoring data, NA – Not available

3.3 Assessment of Nonpoint Sources

In the Straight Creek watershed, both urban and rural nonpoint sources of fecal coliform bacteria were considered. Sources include residential sewage treatment systems, livestock, wildlife, and pets. Sources were identified and enumerated. MapTech collected samples of fecal coliform sources (*i.e.,* wildlife, livestock, and human waste) and enumerated the density of fecal coliform bacteria to support the modeling process, and to expand the database of known fecal coliform sources for purposes of bacterial source tracking (Section 2.6.1). Where appropriate, spatial distribution of sources was also determined.

3.3.1 Private Residential Sewage Treatment

In the U.S. Census questionnaires, housing occupants were asked which type of sewage disposal existed. Houses can be connected to a public sanitary sewer, a septic tank or a cesspool, or the sewage is disposed of in some other way. The Census category “Other Means” includes the houses that dispose of sewage other than by public sanitary sewer or a private septic system. The houses included in this category are assumed to be disposing sewage directly to the stream. Population, housing units, and type of sewage treatment from U.S. Census Bureau were calculated using GIS (Table 3.3).

Table 3.3 Human population, housing units, houses on sanitary sewer, septic systems, and other sewage disposal systems for 2004 in the Straight Creek watershed.

Impaired Segment	Population	Housing Units	Sanitary Sewer	Septic Systems	Other *
Straight Creek	1,353	635	80	339	216

* Houses with sewage disposal systems other than sanitary sewer and septic systems.

Sanitary sewers are piping systems designed to collect wastewater from individual homes and businesses and carry it to a wastewater treatment plant. Sewer systems are designed to carry a specific "peak flow" volume of wastewater to the treatment plant. Within this design parameter, sanitary collection systems are not expected to overflow, surcharge or otherwise release sewage before their waste load is successfully delivered to the wastewater treatment plant.

When the flow of wastewater exceeds the design capacity, the collection system will "back up" and sewage discharges through the nearest escape location. These discharges into the environment are called overflows. Wastewater can also enter the environment through exfiltration caused by line cracks, joint gaps, or breaks in the piping system.

Typical private residential sewage treatment systems (septic systems) consist of a septic tank, distribution box, and drainage field. Waste from the household flows first to the septic tank, where solids settle out and are periodically removed by a septic tank pump-out. The liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried, perforated pipes that comprise the drainage field. Once in the soil, the effluent flows downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal coliform is accomplished primarily by die-off during the time between introduction to the septic system and eventual introduction to naturally occurring waters. Properly designed, installed, and functioning septic systems contribute virtually no fecal coliform to surface waters.

A septic failure occurs when a drain field has inadequate drainage or a "break", such that effluent flows directly to the soil surface, bypassing travel through the soil profile. In this situation the effluent is either available to be washed into waterways during runoff events or is directly deposited in-stream due to proximity. A survey of septic pump-out contractors performed by MapTech showed that failures were more likely to occur in the winter-spring months than in the summer-fall months, and that a higher percentage of system failures were reported because of a back-up to the household than because of a failure noticed in the yard.

MapTech sampled waste from septic tank pump-outs and found an average fecal coliform density of 1,040,000 cfu/100 mL. An average fecal coliform density for human waste of 13,000,000 cfu/g and a total waste load of 75 gal/day/person was reported by Geldreich (1978).

3.3.2 Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the watershed and were the only pets considered in this analysis. Cat and dog populations were derived from American Veterinary Medical Association Center for Information Management demographics in 1997. Dog waste load was reported by Weiskel et al. (1996), while cat waste load was measured. Fecal coliform density for dogs and cats was measured from samples collected throughout Virginia by MapTech. A summary of the data collected is given in Table 3.4. Table 3.5 lists the domestic animal populations for the impairment in the Straight Creek watershed.

Table 3.4 Domestic animal population density, waste load, and fecal coliform density for the Straight Creek watershed.

Type	Population Density (an/house)	Waste load (g/an-day)	FC Density (cfu/g)
Dog	0.534	450	480,000
Cat	0.598	19.4	9

Table 3.5 Estimated domestic animal populations in the Straight Creek watershed.

Impaired Segment	Dogs	Cats
Straight Creek	339	380

3.3.3 Livestock

The predominant types of livestock in the Straight Creek watershed are cattle and poultry although all types of livestock identified were considered in modeling the watershed. Animal populations were based on communication with Department of Mines, Minerals, and Energy (DMME), Daniel Boone Soil and Water District (DBSWCD), landowner input, watershed visits, and review of all publicly available information on animal type and approximate numbers known to exist within Lee County. Table 3.6 gives a summary of livestock populations in the Straight Creek watershed. Values of fecal coliform density of livestock sources were based on sampling performed by MapTech. Reported manure production rates for livestock were taken from ASAE, 1998. A summary of fecal coliform density values and manure production rates is presented in Table 3.7.

Table 3.6 Livestock populations in the Straight Creek watershed.

Impaired Segment	Beef Cattle	Horses	Roosters	Turkeys	Ducks	Geese	Goats
Straight Creek	53	12	40	15	10	15	0

Table 3.7 Average fecal coliform densities and waste loads associated with livestock for Straight Creek watershed.

Type	Waste Load (lb/d/an)	Fecal Coliform Density (cfu/g)
Beef (800 lb)	46.4	101,000
Horse (1,000 lb)	51.0	94,000
Rooster[1]	0.26	586,000
Turkey	0.71	1,332
Duck	0.33	3,500
Goose[2]	0.5	250,000
Goat (140 lb)	5.7	15,000

[1] Based on poultry layer waste load production.
[2] Goose waste load was calculated as 50% greater than that of duck, based on field observations and conversation with Gary Costanzo (Costanzo, 2003).

Fecal coliform produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (*e.g.,* pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. Second, grazing livestock deposit manure directly on the land, where it is available for wash-off during a runoff-producing rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities have drainage systems that divert wash-water and waste directly to drainage ways or streams. No confined animal facilities were identified in the Straight Creek watershed, so only the second and third pathways were considered.

All livestock were expected to deposit some portion of waste on land areas. The percentage of time spent on pasture for beef cattle was reported by the SWCD, NRCS, VADCR, and VCE (Table 3.8). Horses and goats were assumed to be in pasture 100% of the time.

Based on discussions with DBSWCD, VCE, and NRCS, it was concluded that beef cattle were expected to make a significant contribution through direct deposition to streams, where access was available, however, it was also discussed that access would be limited on reclaimed mine benches, where most of the cattle are grazed. The average amount of time spent by beef cattle in stream access areas (*i.e.*, within 50 feet of the stream) for each month is given in Table 3.8.

Table 3.8 Average time beef cows not confined in feedlots spend in pasture and stream access areas per day for Straight Creek watershed.

Month	Pasture (hr)	Stream Access (hr)
January	23.3	0.7
February	23.3	0.7
March	23.0	1.0
April	22.6	1.4
May	22.6	1.4
June	22.3	1.7
July	22.3	1.7
August	22.3	1.7
September	22.6	1.4
October	23.0	1.0
November	23.0	1.0
December	23.3	0.7

3.3.4 Wildlife

The predominant wildlife species in the watershed were determined through consultation with wildlife biologists from the Virginia Department of Game and Inland Fisheries (VDGIF), United States Fish and Wildlife Service (FWS), citizens from the watershed, source sampling, and site visits. Population densities were calculated from data provided by VDGIF and FWS, as well as The Center for Conservation Biology, and are listed in Table 3.9 (Bidrowski, 2004; Farrar, 2003; Fies, 2004; Knox, 2004; Norman, 2004; and Rose and Cranford, 1987). The numbers of animals estimated to be in the Straight Creek watershed are reported in Table 3.10. Habitat and seasonal food preferences were determined based on information obtained from The Fire Effects Information System (http://www.fs.fed.us/database/feis) (1999) and VDGIF (Costanzo, 2003; Norman, 2003; Rose and Cranford, 1987; and VDGIF, 1999). Waste loads were comprised from literature values and discussion with VDGIF personnel (ASAE, 1998; Bidrowski, 2003; Costanzo, 2003; Weiskel et al., 1996; and Yagow, 1999). Where available, fecal coliform densities were based on sampling of wildlife waste performed by MapTech.

The only value that was not obtained from MapTech sampling was for beaver. The fecal coliform density of beaver waste was taken from sampling done for the Mountain Run TMDL development (Yagow, 1999). Percentage of time spent in stream access areas and percentage of waste directly deposited to streams was based on habitat information and location of feces during source sampling. Fecal coliform densities and estimated percentages of time spent in stream access areas (*i.e.*, within 100 feet of stream) are reported in Table 3.11. Table 3.12 summarizes the habitat and fecal production information that was obtained.

Table 3.9 Wildlife population density in Lee (Straight Creek) county.

County	Deer (an/ac of habitat)	Turkey (an/ac)	Goose (an/ac)	Duck (an/ac)	Muskrat (an/ac of habitat)	Raccoon (an/ac of habitat)	Beaver (an/mi of stream)
Lee	0.028	0.016	0.004	0.005	2.75	0.0703	3.8

Table 3.10 Wildlife populations in the Straight Creek watershed.

Impairment	Deer	Turkey	Goose	Duck	Muskrat	Raccoon	Beaver
Straight Creek	409	111	75	94	1,541	354	368

Table 3.11 Average fecal coliform densities and percentage of time spent in stream access areas for wildlife for the Straight Creek watershed.

Animal Type	Fecal Coliform Density (cfu/g)	Portion of Day in Stream Access Areas (%)
Raccoon	2,100,000	5
Muskrat	1,900,000	90
Beaver	1,000	100
Deer	380,000	5
Turkey	1,332	5
Goose	250,000	50
Duck	3,500	75

Table 3.12 Wildlife fecal production rates and habitat for the Straight Creek watershed.

Animal	Waste Load (g/an-day)	Habitat
Raccoon	450	Primary = region within 600 ft of perennial streams Secondary = region between 601 and 7,920 ft from perennial streams Infrequent/Seldom = rest of watershed area including waterbodies (lakes, ponds)
Muskrat	100	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area
Beaver[1]	200	Primary = Perennial streams. Generally flat slope regions (slow moving water), food sources nearby (corn, forest, younger trees) Infrequent/Seldom = rest of the watershed area
Deer	772	Primary = forested, harvested forest land, orchards, grazed woodland, urban grassland, cropland, pasture, wetlands, transitional land Secondary = low density residential, medium density residential Infrequent/Seldom = remaining land use areas
Turkey[2]	320	Primary = forested, harvested forest land, grazed woodland, orchards, wetlands, transitional land Secondary = cropland, pasture Infrequent/Seldom = remaining land use areas
Goose[3]	225	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area
Duck	150	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area

[1]Beaver waste load was calculated as twice that of muskrat, based on field observations.
[2]Waste load for domestic turkey (ASAE, 1998).
[3]Goose waste load was calculated as 50% greater than that of duck, based on field observations and conversation with Gary Costanzo (Costanzo, 2003).

4. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of TMDLs for the Straight Creek watershed, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. In this section, the selection of modeling tools, parameter development, calibration, and model application are discussed.

4.1 Modeling Framework Selection

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions and to perform TMDL allocations. The HSPF model is a continuous simulation model that can account for nonpoint source (NPS) pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities can be explicitly accounted for in the model. The use of HSPF allowed for consideration of seasonal aspects of precipitation patterns within the watershed.

The HSPF model simulates a watershed by dividing it up into a network of stream segments (each referred to in the model as a RCHRES), impervious land areas (IMPLND) and pervious land areas (PERLND). Each subwatershed contains a single RCHRES, modeled as an open channel, and numerous PERLNDs and IMPLNDs, representing the various land uses in that subwatershed. Water and pollutants from the land segments in a given subwatershed flow into the RCHRES in that subwatershed. Point discharges and withdrawals of water and pollutants are simulated as flowing directly to or withdrawing from a particular RCHRES as well. Water and pollutants from a given RCHRES flow into the next downstream RCHRES. The network of RCHRESs is constructed to mirror the configuration of the stream segments found in the physical world. Therefore, activities simulated in one impaired stream segment affect the water quality downstream in the model.

4.2 Model Setup

Because the nearest continuous stream flow data were observed at a USGS station on North Fork Powell River (#03530500), hydrology was calibrated for an area larger than the drainage area of the impaired stream. All water quality modeling (fecal coliform and benthic) was performed only for the impaired (Straight Creek) watershed.

To adequately represent the spatial variation in the Straight Creek watershed, the drainage area was divided into 4 subwatersheds (Figure 4.1). The USGS Station #03530500 on the North Fork Powell River was the outlet for the hydrologic model. This area includes the Straight Creek watershed and the headwaters of the North Fork Powell River. The subwatersheds used in the modeling for Straight Creek and North Fork Powell are shown in Figure 4.1. The area contributing to the bacteria and benthic impairments in Straight Creek includes subwatersheds 6, 7, 8, and 9.

The rationale for choosing subwatersheds was based on the availability of surface flow data and water quality data (fecal coliform and TDS), which were available at specific locations throughout the watershed. Subwatershed outlets were chosen to coincide with monitoring stations, since output from the model can only be obtained at the modeled subwatershed outlets. The spatial division of the watershed allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watershed.

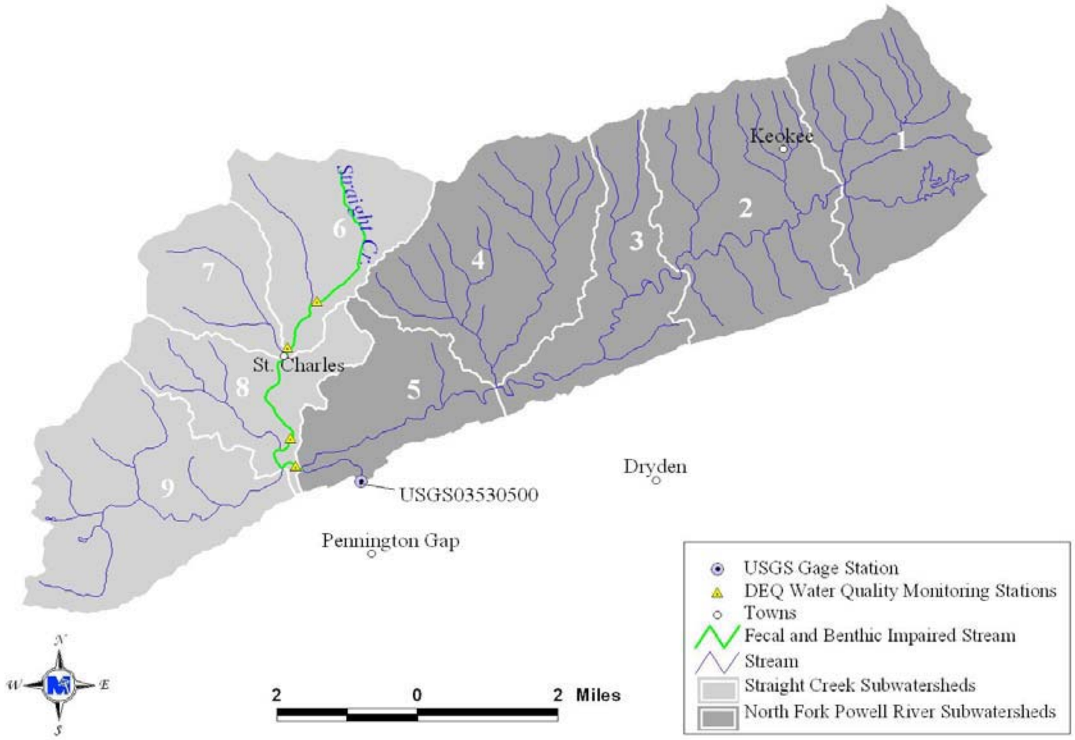

Figure 4.1 Subwatersheds delineated for modeling the hydrology of the North Fork Powell River watershed and the water quality of the Straight Creek watershed.

Using MRLC, U.S. Census Bureau TIGER (Topologically Integrated Geographic Encoding and Referencing), and DMME maps, land use types in the modeled watersheds were identified. The land use types were consolidated into fifteen categories based on similarities in hydrologic features pollutant loadings (Tables 4.1 and 4.2). Within each subwatershed, up to the fifteen land use categories were represented. Each land use had parameters associated with it that described the hydrology of the area (*e.g.,* average slope length) and the behavior of pollutants. These land use types are represented in HSPF as PERLNDs and IMPLNDs. Impervious areas are represented in seven IMPLND types, while there are twelve PERLND types, each with parameters describing a particular land use (Table 4.1 and 4.2). Some IMPLND and PERLND parameters (*e.g.,* slope length) vary with the particular subwatershed in which they are located. Others (*e.g.*, upper zone storage) vary with season to account for plant growth, die-off, and removal.

Table 4.1 Land use categories for the Straight Creek watershed.

TMDL Land use Categories	Pervious / Impervious (%)	Land use Classifications (MRLC Class No. where applicable)
Abandoned Mine Land	Pervious (70%) Impervious (30%)	Land disturbed by mining operations before 1978 and not reclaimed
Active Mining	Pervious (100%)	Land disturbed by mining operations
Barren	Pervious (70%) Impervious (30%)	Bare Rock/Sand/Clay (31) Transitional (33)
Cropland	Pervious (100%)	Row Crops (82)
Commercial	Pervious (80%) Impervious (20%)	Commercial/Industrial/Transportation (23)
Forest	Pervious (100%)	Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43)
Livestock Access	Pervious (100%)	Pasture/Hay (81) near streams
Pasture	Pervious (100%)	Pasture/Hay (81)
Reclaimed	Pervious (100%)	Land regraded and revegetated after mining operations
Residential	Pervious (80%) Impervious (20%)	Low Intensity Residential (21) High Intensity Residential (22)
Roads – paved	Impervious (100%)	Paved roads
Roads – unpaved	Impervious (100%)	Gravel and dirt roads
Water	Pervious (100%)	Open Water (11)
Wetlands	Pervious (100%)	Woody Wetlands (91) Emergent Herbaceous Wetlands (92)

Table 4.2 Contributing land use area for the North Fork Powell River watershed.

Land use	Straight Creek and North Fork Powell River watersheds (acres)
Barren	364
Commercial	43
Cropland	19
Forest	38,940
Livestock Access	4
Pasture/Hay	117
Residential	256
Transitional	0
Water	760
Wetlands	71
Abandoned Mine Land	1,991**
Active Mining	2,675
Reclaimed	167
Roads–paved	63
Roads-unpaved	60
Total	**45,530**

For the purpose of modeling the hydrology and TDS loads from AML, only AML sites outside boundaries of current permitted mining permits were incorporated. It was assumed that AML located in current permit areas would be reclaimed when the permit is released.

4.2.1 Mine Land Hydrology Model Setup

Surface mining requires sediment/runoff retention ponds, which are regulated through the Virginia DMME. The outflow from these ponds is modeled through an additional RCHRES for each subwatershed with a retention pond. The disturbed land area contributing to these ponds was accounted for in the RCHRES. The average revegetated land per year was an input into the model to represent average reclamation efforts completed each year. The locations of these ponds in the Straight Creek watershed are shown in Figure 4.2.

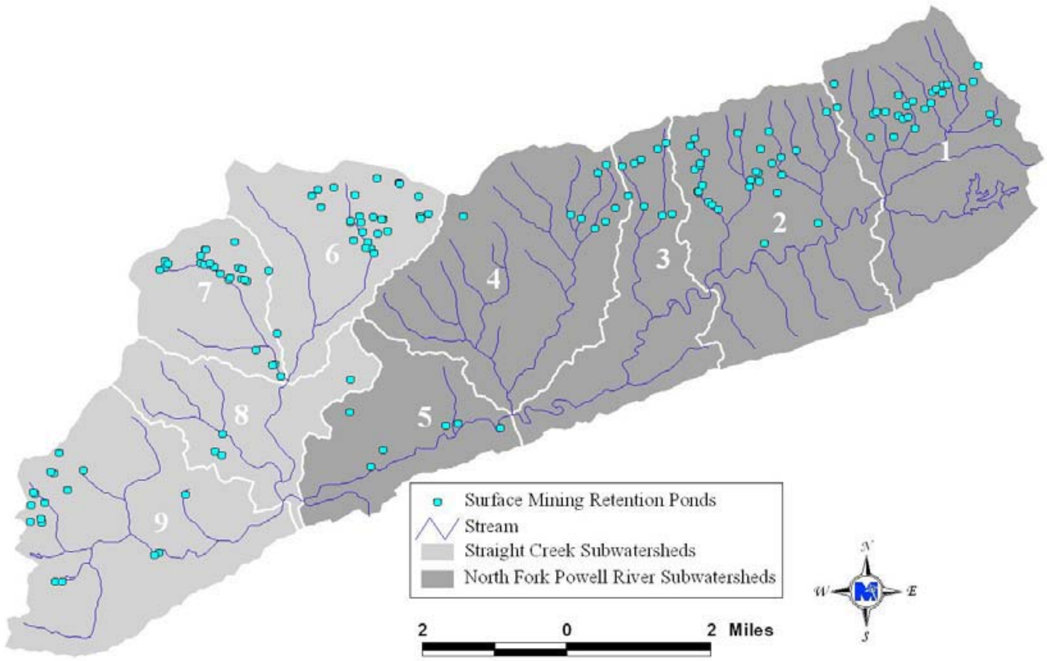

Figure 4.2 Surface runoff retention ponds operational during the calibration time period in the North Fork Powell River and Straight Creek watersheds.

4.2.2 Water Quality Model Setup

Die-off of fecal coliform can be handled implicitly or explicitly. For land-applied fecal matter (fecal matter deposited directly on land), die-off occurring in the field was represented implicitly through model parameters such as the maximum accumulation and the 90% wash off rate, which were adjusted during the calibration of the model. These parameters were assumed to represent not only the delivery mechanisms, but the bacteria die-off as well. Once the fecal coliform entered the stream, the general decay module of HSPF was incorporated, thereby explicitly addressing the die-off rate. The general decay module uses a first order decay function to simulate die-off.

4.3 Source Representation - Fecal Coliform

Both point and nonpoint sources can be represented in the model. In general, point sources are added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources are represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport varies with land use type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (*e.g.*, animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream. These sources are primarily due to animal activity, which varies with the time of day. Direct depositions by nocturnal animals were modeled as being deposited from 6:00 PM to 6:00 AM, and direct depositions by diurnal animals were modeled as being deposited from 6:00 AM to 6:00 PM. Once in stream, die-off is represented by a first-order exponential equation.

Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.,* population). Depending on the time-frame of the simulation being run, different numbers should be used. For modeling Straight Creek fecal coliform loads, data representing 1995 were used for the water quality calibration period (1990-1994). Data representing 2004 were used for the allocation runs in order to represent current conditions for the impairment.

4.3.1 Point Sources

For permitted point discharges, design flow capacities were used for allocation runs. This flow rate was combined with a fecal coliform concentration of 200 cfu/100 mL, where discharges were permitted for fecal control, to ensure that compliance with state water quality standards could be achieved even if permitted loads were at maximum levels. Nonpoint sources of pollution that were not driven by runoff (*e.g.*, direct deposition of fecal matter to the stream by wildlife) were modeled similarly to point sources. These sources, as well as land-based sources, are identified in the following sections.

4.3.2 Private Residential Sewage Treatment

Through GIS, the number of septic systems in the subwatersheds modeled for the Straight Creek watershed was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2000) with the watershed to enumerate the septic systems. Households were then distributed among residential land use types. Each land use area was assigned a number of septic systems based on census data. In Straight Creek there were an estimated 386 septic systems in 1995. During allocation runs, the number of households was projected to 2004 values (based on current Lee County growth rates -- USCB, 2000) resulting in 339 in the Straight Creek watershed (Table 4.3).

Table 4.3 Estimated failing septic systems and straight pipes (2004) for the Straight Creek watershed.

Impaired Segment	Total Septic Systems	Failing Septic Systems	Straight Pipes
Straight Creek	339	140	216

4.3.2.1 Failing Septic Systems

Failing septic systems were assumed to deliver all effluent to the soil surface where it was available for wash-off during a runoff event. In accordance with estimates from Raymond B. Reneau, Jr. of the Crop and Soil Environmental Sciences Department at Virginia Tech, a 40% failure rate for systems designed and installed prior to 1964, a 20% failure rate for systems designed and installed between 1964 and 1984, and a 5% failure rate on all systems designed and installed after 1984 was used in development of TMDLs for the Straight Creek watershed (Reneau, 2000). Total septic systems in each category were calculated using U.S. Census Bureau block demographics. The applicable failure rate was multiplied by each total and summed to get the total failing septic systems per subwatershed. The fecal coliform density for septic system effluent was multiplied by the average design load for the septic systems in the subwatershed to determine the total load from each failing system. Additionally, the loads were distributed seasonally based on a survey of septic pump-out contractors to account for more frequent failures during wet months.

4.3.2.2 Uncontrolled Discharges

Uncontrolled discharges were estimated using 1990 U.S. Census Bureau block demographics. Houses listed in the Census sewage disposal category "other means" were assumed to be disposing sewage via uncontrolled discharges such as straight pipes. Corresponding block data and subwatershed boundaries were intersected to determine an estimate of uncontrolled discharges in each subwatershed. After public comment on the estimated numbers indicated that uncontrolled discharges were not being represented adequately, an informal survey was conducted by local VDH personnel, and the numbers were adjusted accordingly (Table 4.3). Fecal coliform loads for each discharge were calculated based on the fecal density of human waste and the waste load for the average size household in the subwatershed. The loadings from uncontrolled discharges were applied directly to the stream in the same manner that point sources are handled in the model. Total dissolved solids (TDS) concentration from human waste for each discharge was estimated as 500 mg/L (Metcalf and Eddy, 1991). A total suspended solids concentration from human waste was estimated as 320 mg/L (Lloyd, 2004). The methods of incorporating TDS and TSS loads into the model are discussed further in Chapter 9.

4.3.2.3 Sewer System Overflows

During the model calibration and allocation periods, there were no reported sewer overflows in the Straight Creek watershed.

4.3.3 Livestock

Fecal coliform produced by livestock can enter surface waters through four pathways: land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Due to the lack of confined animal facilities in this watershed, only deposition on land and direct deposition to streams are accounted for in the model. The number of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Livestock numbers determined for 2004 were used for the allocation runs, while these numbers were projected back to 1995 for the calibration and validation runs for Straight Creek. The numbers are based on data provided by Daniel Boone SWCD, DMME, NRCS, and verbal communication with the local community. Growth rates were taken into account in Lee County as determined from data reported by the Virginia Agricultural Statistics Service (VASS, 1995 and VASS, 2002). The fecal coliform density in as-excreted manure was used to calculate the load for deposition on land and to streams (Table 3.7).

4.3.3.1 Deposition on Land

For cattle, the amount of waste deposited on land per day was a proportion of the total waste produced per day. The proportion was calculated based on the study entitled "Modeling Cattle Stream Access" conducted by the Biological Systems Engineering Department at Virginia Tech and MapTech, Inc. for VADCR. The proportion was based on the amount of time spent in pasture, but not in close proximity to accessible streams, and was calculated as follows:

Proportion = [(24 hr) – (time in confinement) – (time in stream access areas)]/(24 hr)

All other livestock (horse and goat) were assumed to deposit all feces on pasture. The total amount of fecal matter deposited on the pasture land use type was area-weighted.

4.3.3.2 Direct Deposition to Streams

The amount of waste deposited in streams by livestock each day was a proportion of the total waste produced per day by cattle. First, the proportion of manure deposited in "stream access" areas was calculated based on the "Modeling Cattle Stream Access" study. The proportion was calculated as follows:

Proportion = (time in stream access areas)/(24 hr)

For the waste produced on the "stream access" land use, 30% of the waste was modeled as being directly deposited in the stream and 70% remained on the land segment adjacent to the stream. The 70% was treated as manure deposited on land. However, applying it in a separate land-use area (stream access) allows the model to consider the proximity of the deposition to the stream. The 30% that was directly deposited to the stream was modeled in the same way that point sources are handled in the model.

4.3.4 Biosolids

Investigation of VDH data indicated that no biosolids applications have occurred within the Straight Creek watershed. For model calibration, biosolids were not included.

4.3.5 Wildlife

For each species, a GIS habitat layer was developed based on the habitat descriptions that were obtained (Section 3.3.4). Examples of these layers are shown in Figure 4.3. This layer was overlaid with the land use layer and the resulting area was calculated for each land use in each subwatershed. The number of animals per land segment was determined by multiplying the area by the population density. Fecal coliform loads for each land segment were calculated by multiplying the waste load, fecal coliform densities, and number of animals for each species.

Seasonal distribution of waste was determined using seasonal food preferences for deer and turkey. Goose and duck populations were varied based on migration patterns, but the load available for delivery to the stream was never reduced below 40% of the maximum to account for the resident population of birds. For each species, a portion of the total waste load was considered to be land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (Table 3.12). For all animals other than beaver, it was estimated that 5% of fecal matter produced while in stream access areas was directly deposited to the stream. For beaver, it was estimated that 100% of fecal matter would be directly deposited to streams. No long-term (1995–2004) projections were made to wildlife populations, as there was no available data to support such adjustments.

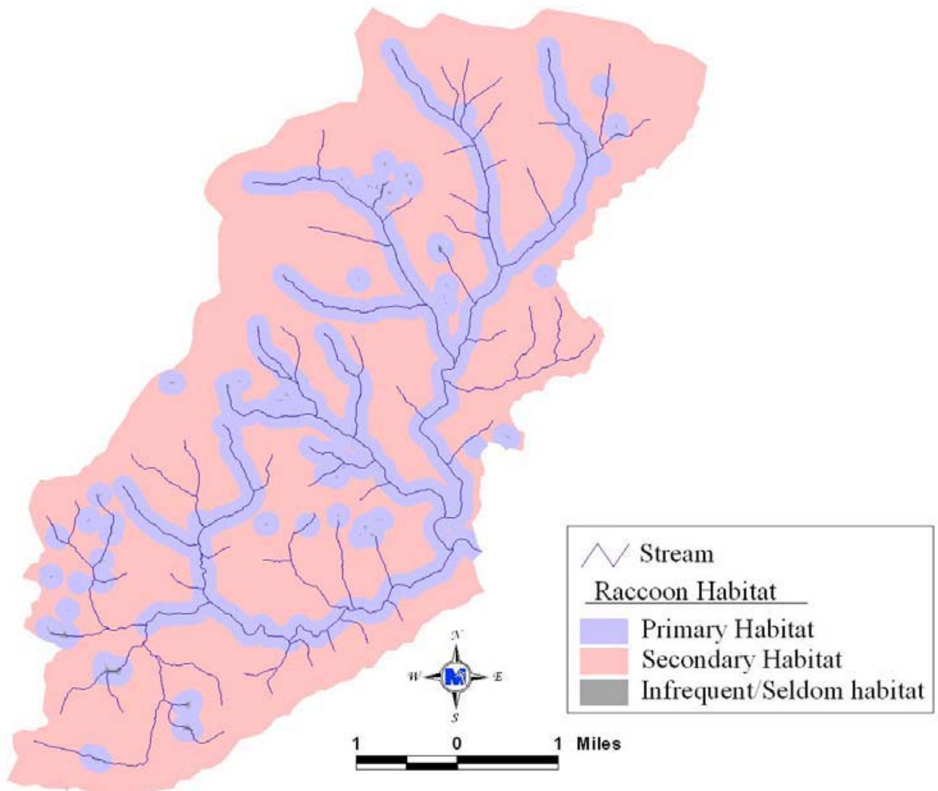

Figure 4.3 Example of raccoon habitat layer in the Straight Creek watershed as developed by MapTech.

4.3.6 Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals/house), waste load, and fecal coliform density are reported in Section 3.3.2. Waste from pets was distributed in the residential land uses. The locations of households were taken from census reports from 1990 and 2000 (USCB, 1990, 2000). Using GIS, the land use and household layers were overlaid, which resulted in number of households per land use. The number of animals per land use was determined by multiplying the number of households by the population density. The amount of fecal coliform deposited daily by pets in each land use segment was calculated by multiplying the waste load, fecal coliform density, and number of animals of both cats and dogs. The waste load was assumed not to vary seasonally. The population figures for cats and dogs were projected from 1990 data to 1995 and 2004.

4.4 Stream Characteristics

HSPF requires that each stream reach be represented by constant characteristics (*e.g.,* stream geometry and resistance to flow). In order to determine a representative stream profile for each stream reach, cross-sections were surveyed at locations that were representative of the stream for the modeled subwatersheds.

Most of the sections exhibited distinct flood plains with pitch and resistance to flow significantly different from that of the main channel slopes. The streambed, channel banks, and flood plains were identified. Once identified, the streambed width and slopes of channel banks and flood plains were calculated using the survey data. A representative stream profile for each surveyed cross-section was developed and consisted of a trapezoidal channel with pitch breaks at the beginning of the flood plain (Figure 4.4). With this approach, the flood plain can be represented differently from the streambed. To represent the entire reach, profile data collected at each end of the reach were averaged.

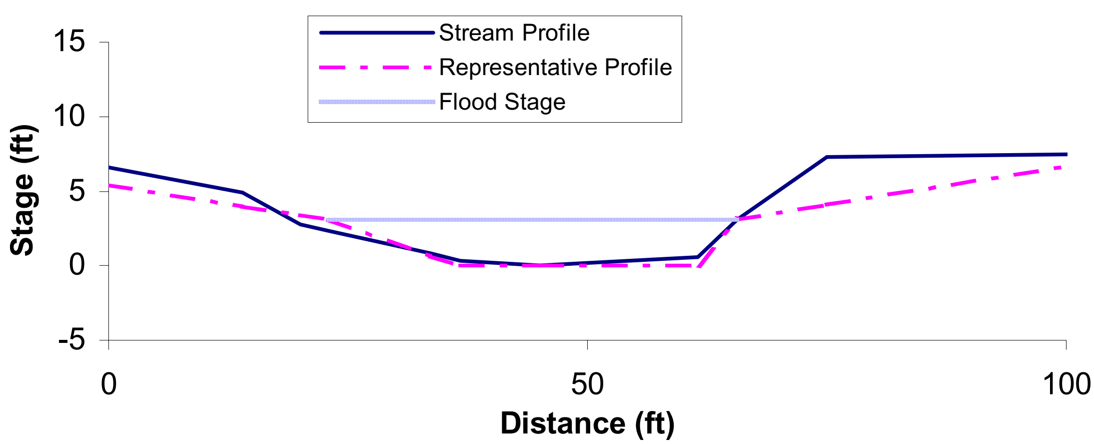

Figure 4.4 Stream profile representation in HSPF.

Conveyance was used to facilitate the calculation of discharge in the reach with different values for resistance to flow (*i.e.,* Manning's *n*) assigned to the flood plains and streambeds. The conveyance was calculated for each of the two flood plains and the main channel, then these were added together to obtain a total conveyance. Calculation of conveyance was performed following the procedure described by Chow (1959). The total conveyance was then multiplied by the square root of the average reach slope to obtain the discharge (ft^3/s) at a given depth.

A key parameter used in the calculation of conveyance is the Manning's roughness coefficient, *n*. There are many ways to estimate this parameter for a section. The method first introduced by Cowan (1956) and adopted by the Soil Conservation Service (1963) was used to estimate Manning's *n*. This procedure involves a 6-step process of evaluating the properties of the reach, which is explained in more detail by Chow (1959). Field data describing the channel bed, bank stability, vegetation, obstructions, and other pertinent parameters were collected. Photographs were also taken of the sections while in the field. Once the field data were collected, they were used to estimate the Manning's roughness coefficient for the section observed. The pictures were compared to pictures contained in Chow (1959) for validation of the estimates of the Manning's *n* for each section.

The result of the field inspections of the reach sections was a set of characteristic slopes (channel sides and field plains), bed widths, heights to flood plain, and Manning's roughness coefficients. Average reach slope and reach length were obtained from GIS layers of the watershed, which included elevation from Digital Elevation Models (DEMs) and a stream-flow network developed from high resolution National Hydrologic Dataset (NHD) data. These data were used to derive the Hydraulic Function Tables (F-tables) used by the HSPF model (Table 4.4). The F-tables consist of four columns: depth (ft), area (ac), volume (ac-ft), and outflow (ft^3/s). The depth represents the possible range of flow, with a maximum value beyond what would be expected for the reach. The area listed is the surface area of the stream reach or reservoir in acres. The volume corresponds to the total volume of the flow in the reach, and is reported in acre-feet. The outflow is simply the stream discharge, in cubic feet per second. The HSPF model calculates discharge based on volume of water in the reach. For the case of impoundments that were modeled, a minimum volume was set based on design parameters of the pond. During periods of no discharge from the pond, the only pathway for removal of water from the pond was evaporation.

Table 4.4 Example of an "F-table" calculated for the HSPF Model.

Depth (ft)	Area (ac)	Volume (ac-ft)	Discharge (cfs)
0	0	0	0
0.35	3.09	25.63	0.04
0.7	12.96	39.76	23.87
1.05	13.64	52.06	45.84
1.4	14.37	65.89	72.44
1.75	15.15	81.35	102.9
2.1	15.98	98.56	136.69
2.45	16.87	117.64	173.39
2.8	17.8	138.71	212.7
3.15	18.78	161.86	254.34
3.5	19.82	187.24	298.12
3.85	19.87	190.67	343.86
9.5	20.75	248.72	1275.84
15.15	21.63	311.76	2464.83
20.8	22.52	379.77	3861.02
26.45	23.4	452.77	5454.18
32.1	24.28	530.75	7244.12

4.5 Selection of Representative Modeling Period

Selection of the modeling period was based on three factors: availability of data (discharge and water quality), the degree of land-disturbing activity, and the need to represent critical hydrological conditions. Using these criteria, modeling periods were selected for hydrology calibration, water quality calibration, and modeling of allocation scenarios.

For the North Fork Powell River, flow data were available at USGS Station #03530500 during the period 10/1/1944 through 9/30/1951, 10/1/1978 through 9/30/1981, and 10/1/1993 through 10/3/1995. A linear regression was also performed on this data using continuous data from USGS Station #03531500 on the Powell River. The resulting data were continuous daily flow values at USGS Station #03530500 in the North Fork Powell River at Pennington Gap from 10/1/1944 through 9/30/2003. Fecal coliform data for

Straight Creek were available in the period from 7/11/1990 through 3/12/2001 at various locations throughout the watershed.

Much of the data used to develop the model inputs for modeling water quality is time-dependent. Depending on the time frame of the simulation being run, the model was varied appropriately. Based on a review of mine permit anniversary reports, it was evident that significant landform alterations started to occur in the Straight Creek and the North Fork Powell River watersheds in 1997 (Figures 4.5 and 4.6). The hydrographic landscape of the watershed was relatively stable during the hydrology calibration periods, 10/1/1991-3/31/1995 for the North Fork Powell River. Data representing these periods were used to develop the hydrologic models used in this study.

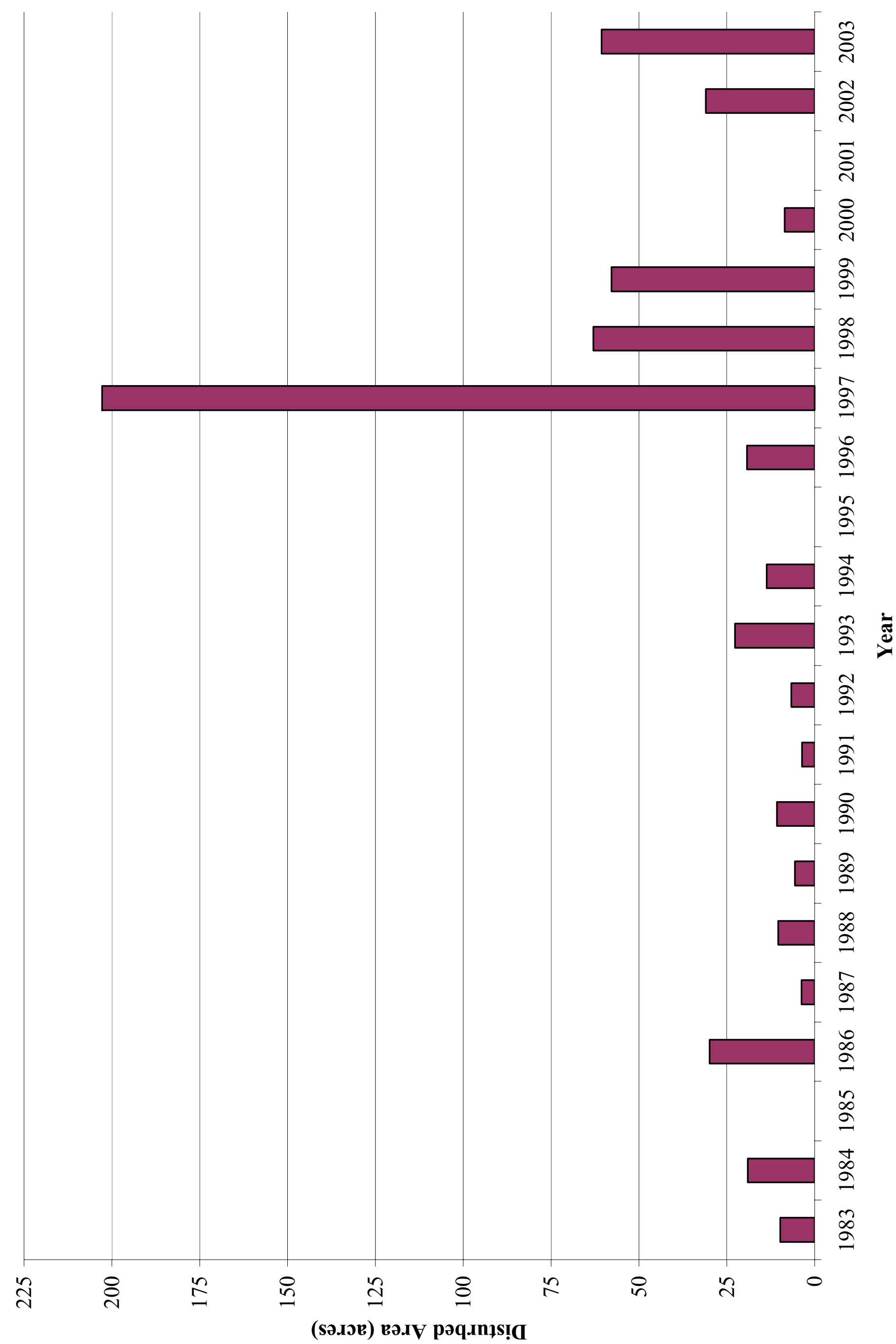

Figure 4.5 Annual land disturbed by mining practices in the Straight watershed.

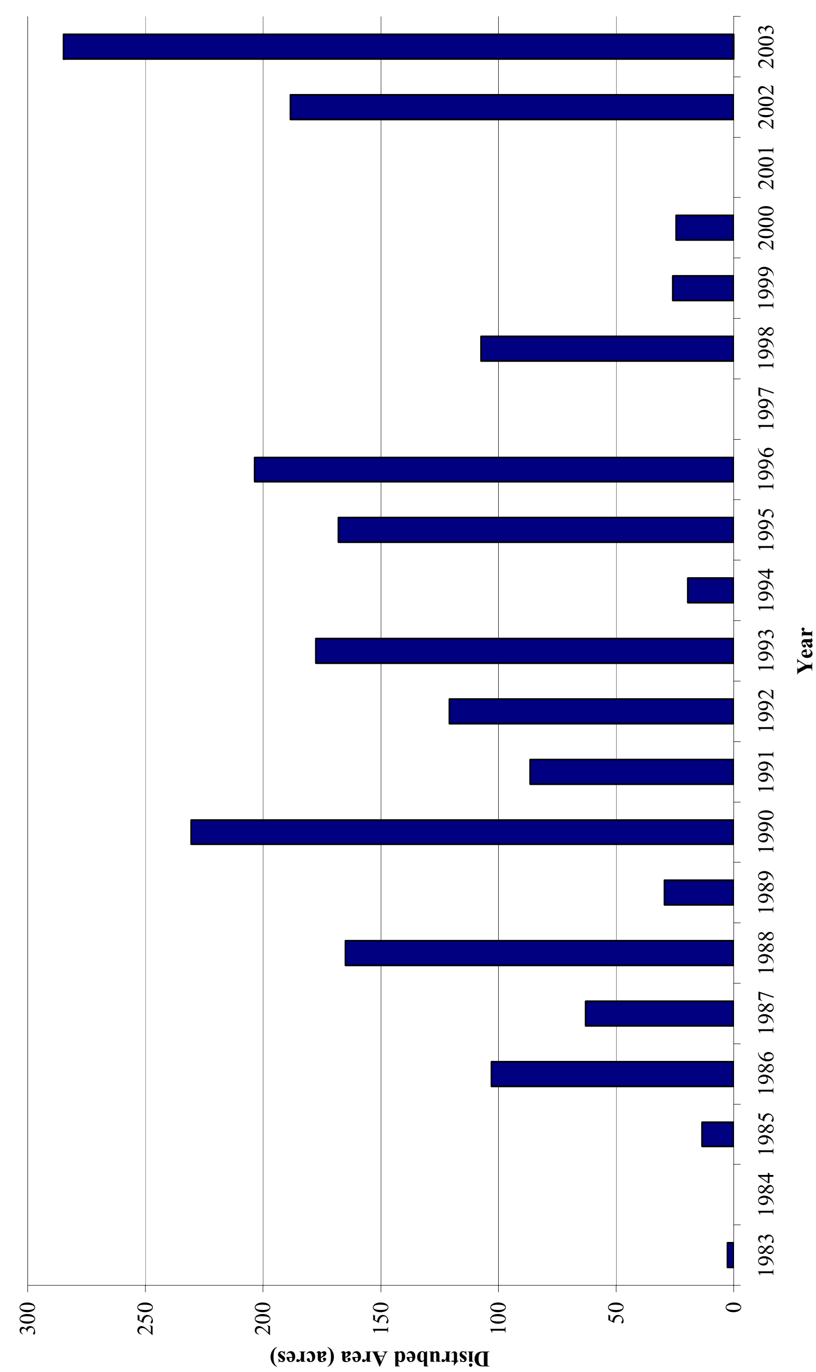

Figure 4.6 Annual land disturbed by mining practices in the North Fork Powell River watershed.

A representative period for water quality calibration for Straight Creek was selected with consideration given to the hydrology calibration period, availability of water quality data, the total land disturbed due to mining operations, and the VADEQ assessment period from July 1992 through June 1997 that led to the inclusion of the Straight Creek segment on the *1998 Section 303(d) Total Maximum Daily Load Priority List and Report* (VADEQ, 1998). With these criteria in mind, the modeling period for fecal coliform water quality calibration was 10/1/1990 through 9/29/1994 (Table 4.5). No fecal coliform water quality validation was performed due to the short timeframe of land use stability. It was determined that using all available data for calibration would result in a more accurate model.

Table 4.5 Summary of modeling time periods for the Straight Creek watershed.

Impairment	Hydrology Calibration	Water Quality (FC) Calibration
Straight Creek	10/1/1991 to 3/31/1995	10/1/1990 to 9/29/1994

The allocation precipitation time periods were selected to coincide with the calibration time periods. Modeling during the calibration periods provides the highest confidence in allocation results.

4.6 Sensitivity Analysis

Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.,* seasonal and spatial variability of waste production rates for wildlife, livestock, septic system failures, uncontrolled discharges, background loads, and point source loads).

Sensitivity analyses were run on both hydrologic and water quality parameters. The parameters adjusted for the hydrologic sensitivity analyses are presented in Table 4.6 with base values for the model runs given. The parameters were typically adjusted to -50%, -10%, 10%, and 50% of the base value. Where an increase of 50% exceeded the maximum value for the parameter, the maximum value was used and the parameters increased over the base value were reported. The model was run for the hydrology calibration time period. The hydrologic quantities of greatest interest in modeling NPS pollutants are those that govern peak (high) flows and low flows. Peak flows, being a function of runoff, are important because they are directly related to the transport of NPS pollutants from the land surface to the stream. Peak flows were most sensitive to changes in the parameters governing infiltration such as INFILT (Infiltration) and MON-LZETP (Monthly Lower Zone Evapotranspiration) and AGWRC (Groundwater Recession Rate). To a lesser extent peak flows were sensitive to UZSN (Upper Zone Storage), LZSN (Lower Zone Storage), and direct ET from shallow groundwater (AGWETP). Low flows are important in a water quality model because they control the level of dilution during dry periods. Parameters with the greatest influence on low flows (as evidenced by their influence in the Low Flows and Summer Flow Volume statistics) were AGWRC, INFILT, INTERCEP (interception), MON-LZETP, DEEPFR (Losses to Deep Aquifers) and, to a lesser extent, BASETP (Evapotranspiration from Base Flow). The responses of these and other hydrologic outputs are reported in Table 4.7

Table 4.6 Base parameter values used to determine Straight Creek hydrologic model response.

Parameter	Description	Units	Base Value
AGWRC	Active Groundwater Coefficient	1/day	0.945
BASETP	Base Flow Evapotranspiration	---	0.0345
CEPSC	Interception Storage Capacity	in	0.01 – 0.2
DEEPFR	Fraction of Deep Groundwater	---	0.0 – 0.50
INFILT	Soil Infiltration Capacity	in/hr	0.001 – 0.1154
INTFW	Interflow Inflow	---	1.3
KVARY	Groundwater Recession Coefficient	1/day	0.0
LZSN	Lower Zone Nominal Storage	in	2.0
MON-LZETP	Monthly Lower Zone Evapotranspiration	---	0.01 – 0.8
NSUR	Manning's *n* for Overland Flow	---	0.1
UZSN	Upper Zone Storage Capacity	in	0.05 – 9.952

Table 4.7 Sensitivity analysis results for Straight Creek for hydrologic model parameters (% difference).

Model Parameter	Parameter Change (%)	Total Flow	High Flows	Low Flows	Winter Flow Volume	Spring Flow Volume	Summer Flow Volume	Fall Flow Volume	Total Storm Volume
AGWRC[1]	0.85	1.29	35.89	-40.33	25.03	-8.35	-25.40	7.37	23.90
AGWRC[1]	0.92	1.05	21.64	-25.28	21.38	-5.21	-22.34	2.17	17.68
AGWRC[1]	0.96	0.71	9.74	-12.30	13.20	-0.80	-13.84	-4.04	10.07
AGWRC[1]	0.999	-33.52	-37.89	-24.24	-38.77	-41.76	-32.28	-3.86	-32.37
BASETP	-50	0.14	-0.19	0.33	-0.46	0.41	1.11	-0.47	-0.15
BASETP	-10	0.03	-0.04	0.07	-0.09	0.08	0.22	-0.09	0.02
BASETP	10	-0.03	0.04	-0.07	0.09	-0.08	-0.22	0.10	-0.07
BASETP	50	-0.13	0.20	-0.34	0.47	-0.41	-1.12	0.49	-0.08
DEEPFR	-50	0.44	0.33	0.49	0.42	0.43	0.50	0.46	0.43
DEEPFR	-10	0.09	0.07	0.10	0.08	0.09	0.10	0.09	0.09
DEEPFR	10	-0.09	-0.07	-0.10	-0.08	-0.09	-0.10	-0.09	-0.09
DEEPFR	50	-0.44	-0.33	-0.49	-0.42	-0.43	-0.50	-0.46	-0.43
INFILT	-50	-0.65	22.51	-13.31	10.63	-1.12	-19.62	0.23	0.95
INFILT	-10	-0.14	2.57	-1.56	1.55	-0.09	-3.09	-0.16	-0.12
INFILT	10	0.14	-2.24	1.25	-1.38	0.12	2.68	0.26	0.13
INFILT	50	0.61	-8.24	4.45	-5.06	0.28	10.12	1.61	0.63
INTFW	-50	0.01	0.07	-0.05	0.06	-0.001	-0.05	-0.002	0.02
INTFW	-10	0.03	0.29	-0.20	0.24	-0.004	-0.21	-0.001	0.08
INTFW	10	0.05	0.47	-0.30	0.36	-0.01	-0.32	-0.01	0.07
INTFW	50	0.07	0.66	-0.42	0.49	-0.01	-0.42	-0.02	0.07
LZSN	-50	4.07	14.07	-5.47	11.75	7.15	-7.16	-5.70	3.92
LZSN	-10	0.56	1.71	-0.96	1.39	1.26	-0.76	-1.28	0.03
LZSN	10	-0.50	-1.47	0.84	-1.18	-1.16	0.63	1.15	-0.23
LZSN	50	-2.44	-6.15	2.57	-4.88	-5.06	1.74	3.88	-0.59
MON-INTERCEP	-50	2.21	-3.40	4.70	-3.87	3.19	12.00	0.56	0.21
MON-INTERCEP	-10	0.31	-0.63	0.89	-0.75	0.43	2.13	0.03	0.04
MON-INTERCEP	10	-0.27	0.61	-0.85	0.72	-0.37	-1.89	-0.08	-0.12
MON-INTERCEP	50	-1.17	3.03	-4.94	3.54	-1.21	-9.20	-1.09	0.32
MON-LZETP	-50	21.04	22.12	29.04	29.85	8.78	7.88	48.45	-2.31
MON-LZETP	-10	4.73	3.26	8.07	5.99	1.90	3.10	10.96	-0.09
MON-LZETP	10	-0.51	-0.26	-0.91	-0.65	-0.22	-0.35	-1.14	0.43
MON-LZETP	50	-2.74	-1.39	-4.81	-3.53	-1.17	-1.85	-5.95	1.76
MON-MANNING	-50	0.02	0.44	-0.14	0.19	-0.001	-0.18	-0.01	0.04
MON-MANNING	-10	0.003	0.07	-0.02	0.03	0.0001	-0.03	-0.002	0.01
MON-MANNING	10	-0.003	-0.06	0.02	-0.03	-0.002	0.03	0.005	-0.005
MON-MANNING	50	-0.01	-0.28	0.08	-0.12	-0.003	0.12	0.01	-0.02
MON-UZSN	-50	1.74	7.60	-2.67	5.71	1.49	-2.55	-0.74	2.82
MON-UZSN	-10	0.30	1.25	-0.47	1.07	0.28	-0.48	-0.30	0.50
MON-UZSN	10	-0.29	-1.21	0.45	-1.07	-0.27	0.45	0.38	-0.45
MON-UZSN	50	-1.38	-5.32	2.07	-4.85	-1.51	1.98	2.15	-1.79

[1]Actual parameter value used

The models were run during the corresponding water quality calibration time period for the fecal coliform water quality sensitivity analysis. The three parameters impacting the model's water quality response (Table 4.8) were increased and decreased by amounts that were consistent with the range of values for the parameter.

Since the water quality standard for fecal coliform bacteria is based on concentrations rather than loadings, it was considered necessary to analyze the effect of source changes on the monthly geometric-mean fecal coliform concentration. A monthly geometric mean was calculated for all months during the simulation period, and the values for each month were averaged. Deviations from the base run are given in Table 4.9. All results are plotted by month in Figure 4.7 through Figure 4.9.

In addition to analyzing the sensitivity of the model response to changes in model parameters, the response of the model to changes in land-based and direct loads was analyzed. The impacts of land-based and direct load changes on the annual load are presented in Figure 4.10, while impacts on the monthly geometric mean are presented in Figures 4.11 and 4.12.

It is evident from Figure 4.10 that the model predicts a linear relationship between increased fecal coliform concentrations in both land and direct applications, and total load reaching the stream. For Straight Creek a 100% increase in the land applied loads results in a 32% increase of in-stream loads, while a 100% increase in direct loads results in an increase of approximately 69% for in-stream loads.

The sensitivity analysis of geometric mean concentrations in Figures 4.11 and 4.12 showed that direct loads had the greatest impact, with land-applied loads having a lesser, but measurable impact.

Table 4.8 Base parameter values used to determine water quality model response for the Straight Creek.

Parameter	Description	Units	Base Value
MON-SQOLIM	Maximum FC Accumulation on Land	FC/ac	30
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	1.0
FSTDEC	In-stream First Order Decay Rate	1/day	0.65

Table 4.9 Percent change in average monthly *E. coli* geometric mean for the years 1990-1994 for Straight Creek.

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly *E. coli* Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	18.95	23.92	18.67	27.77	28.19	37.65	49.82	42.87	42.64	42.62	36.49	18.94
FSTDEC	-10	3.67	4.41	3.59	5.05	5.13	6.41	7.77	7.10	7.02	7.09	6.23	3.62
FSTDEC	10	-2.97	-3.50	-2.90	-3.98	-4.04	-4.93	-5.81	-5.40	-5.33	-5.40	-4.79	-2.92
FSTDEC	50	-14.61	-16.68	-14.22	-18.73	-19.01	-22.34	-25.32	-24.07	-23.72	-24.12	-21.79	-14.24
SQOLIM	-50	-1.15	-1.70	-1.32	-1.15	-1.75	-0.57	-0.91	-1.15	-0.78	-1.13	-1.69	-2.21
SQOLIM	-25	-0.43	-0.65	-0.49	-0.42	-0.68	-0.22	-0.34	-0.46	-0.30	-0.48	-0.70	-0.93
SQOLIM	50	0.61	0.93	0.68	0.56	0.98	0.30	0.44	0.69	0.42	0.82	1.17	1.61
SQOLIM	100	1.02	1.52	1.10	0.90	1.60	0.49	0.72	1.17	0.70	1.48	2.07	2.92
WSQOP	-50	1.29	1.09	1.15	1.43	1.58	0.42	0.41	1.17	0.72	1.29	1.13	1.32
WSQOP	-10	0.19	0.17	0.17	0.20	0.24	0.06	0.05	0.16	0.09	0.17	0.17	0.21
WSQOP	10	-0.17	-0.16	-0.16	-0.18	-0.22	-0.05	-0.05	-0.14	-0.08	-0.15	-0.15	-0.20
WSQOP	50	-0.70	-0.69	-0.68	-0.72	-0.92	-0.22	-0.19	-0.54	-0.31	-0.57	-0.61	-0.87

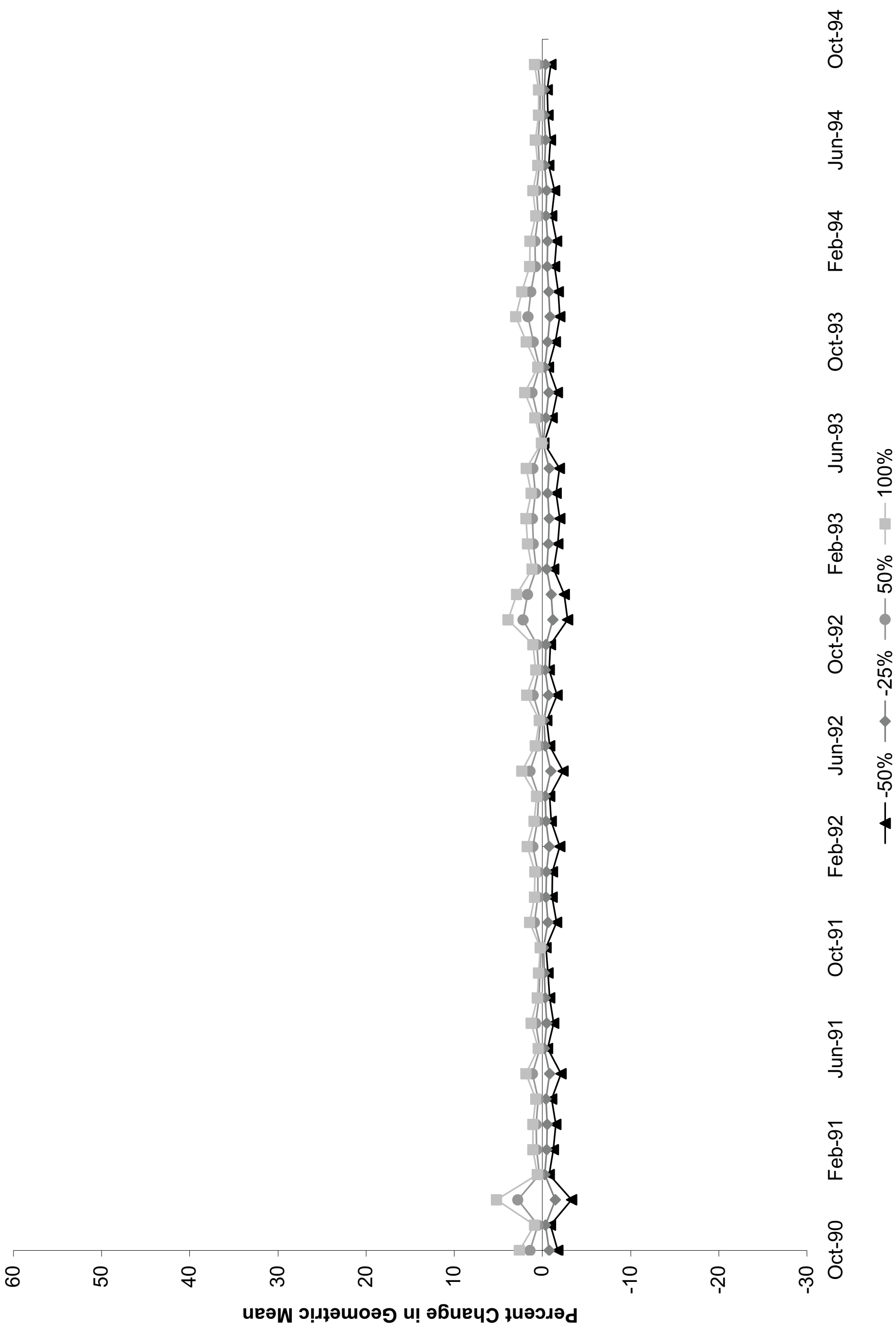

Figure 4.7 Results of sensitivity analysis on monthly geometric-mean concentrations in the Straight Creek watershed, as affected by changes in maximum FC accumulation on land (MON-SQOLIM).

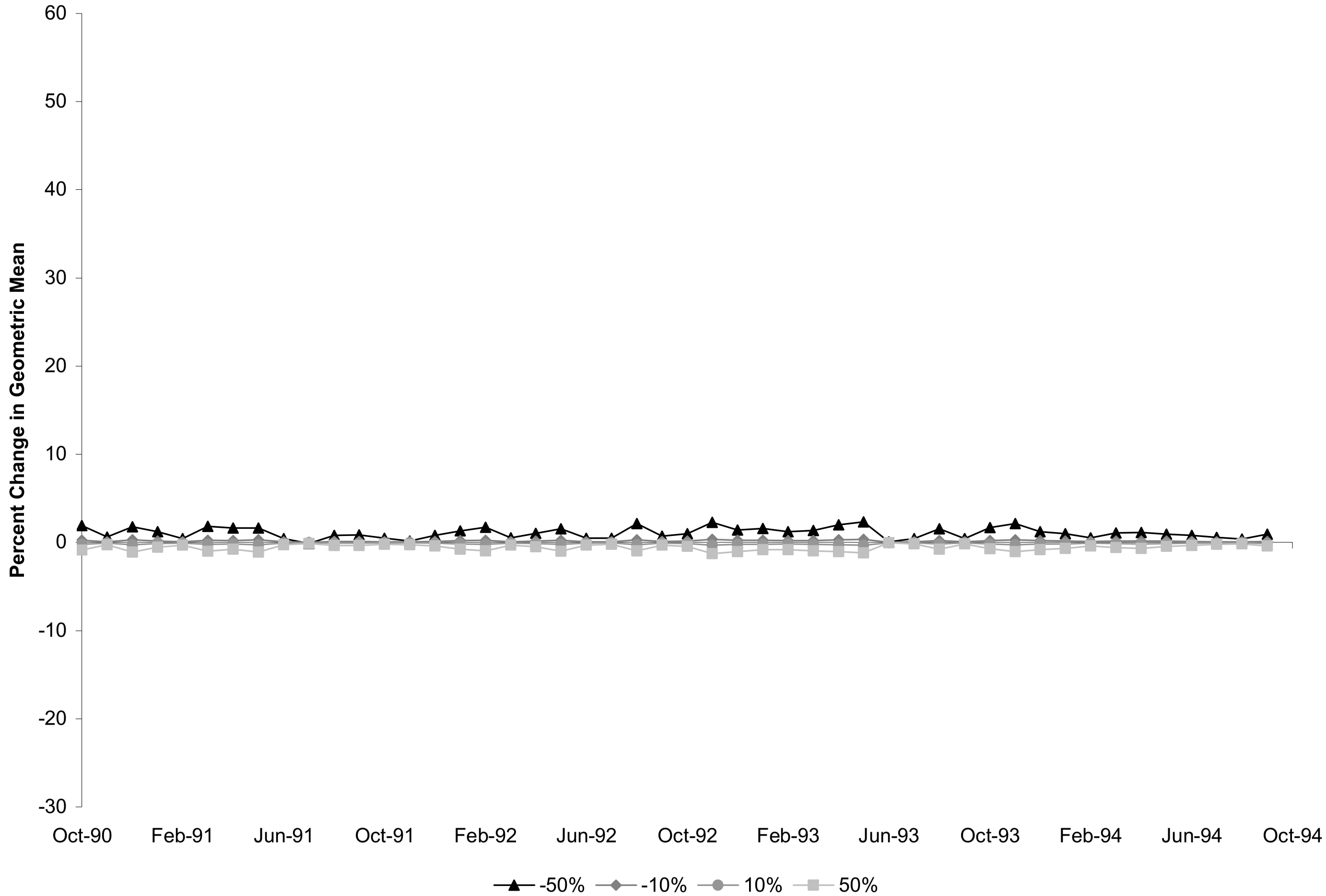

Figure 4.8 Results of sensitivity analysis on monthly geometric-mean concentrations in the Straight Creek watershed, as affected by changes in the wash-off rate for FC fecal coliform on land surfaces (WSQOP).

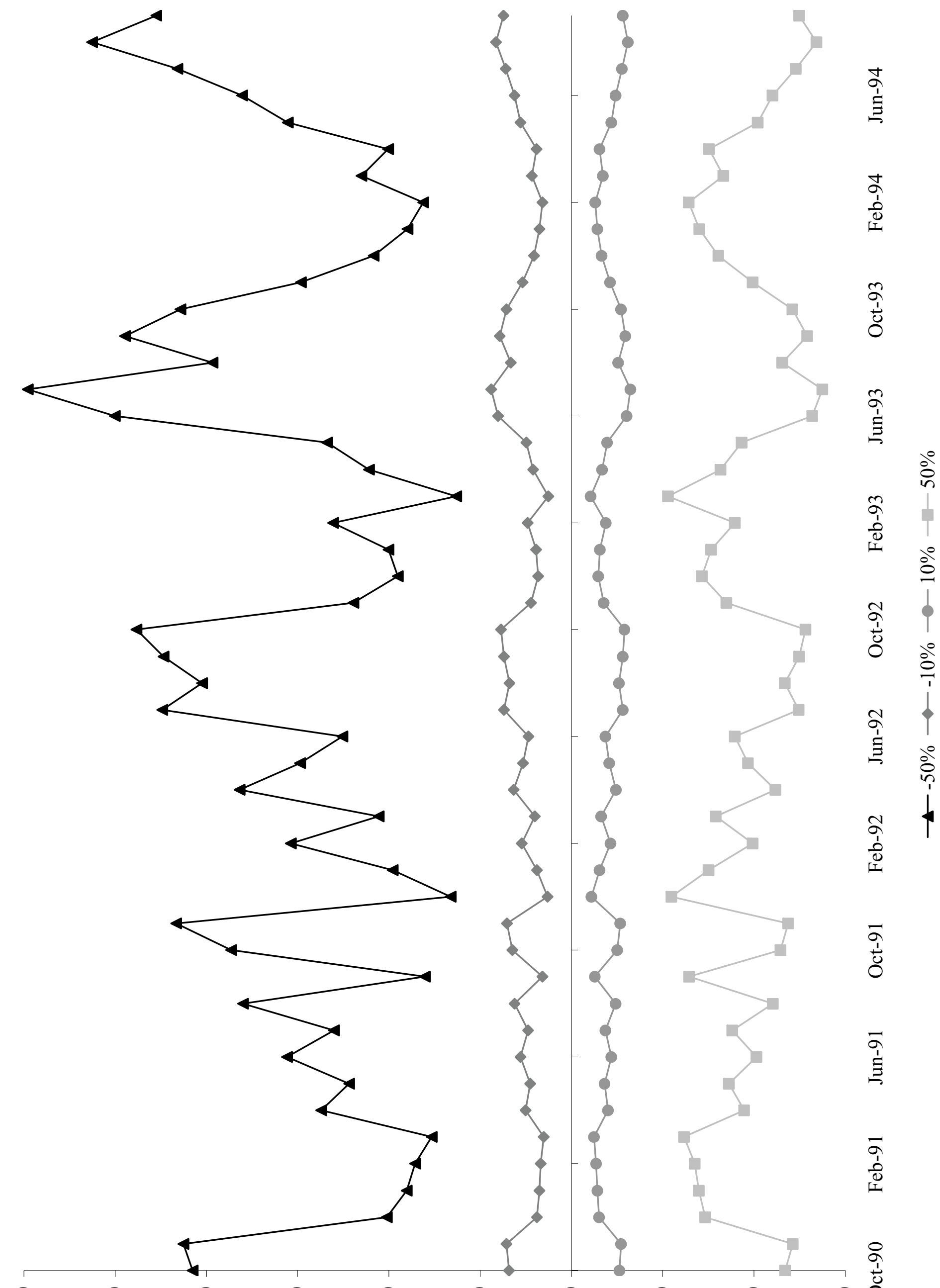

Figure 4.9 Results of sensitivity analysis on monthly geometric-mean concentrations in the Straight Creek watershed, as affected by changes in the in-stream first-order decay rate (FSTDEC).

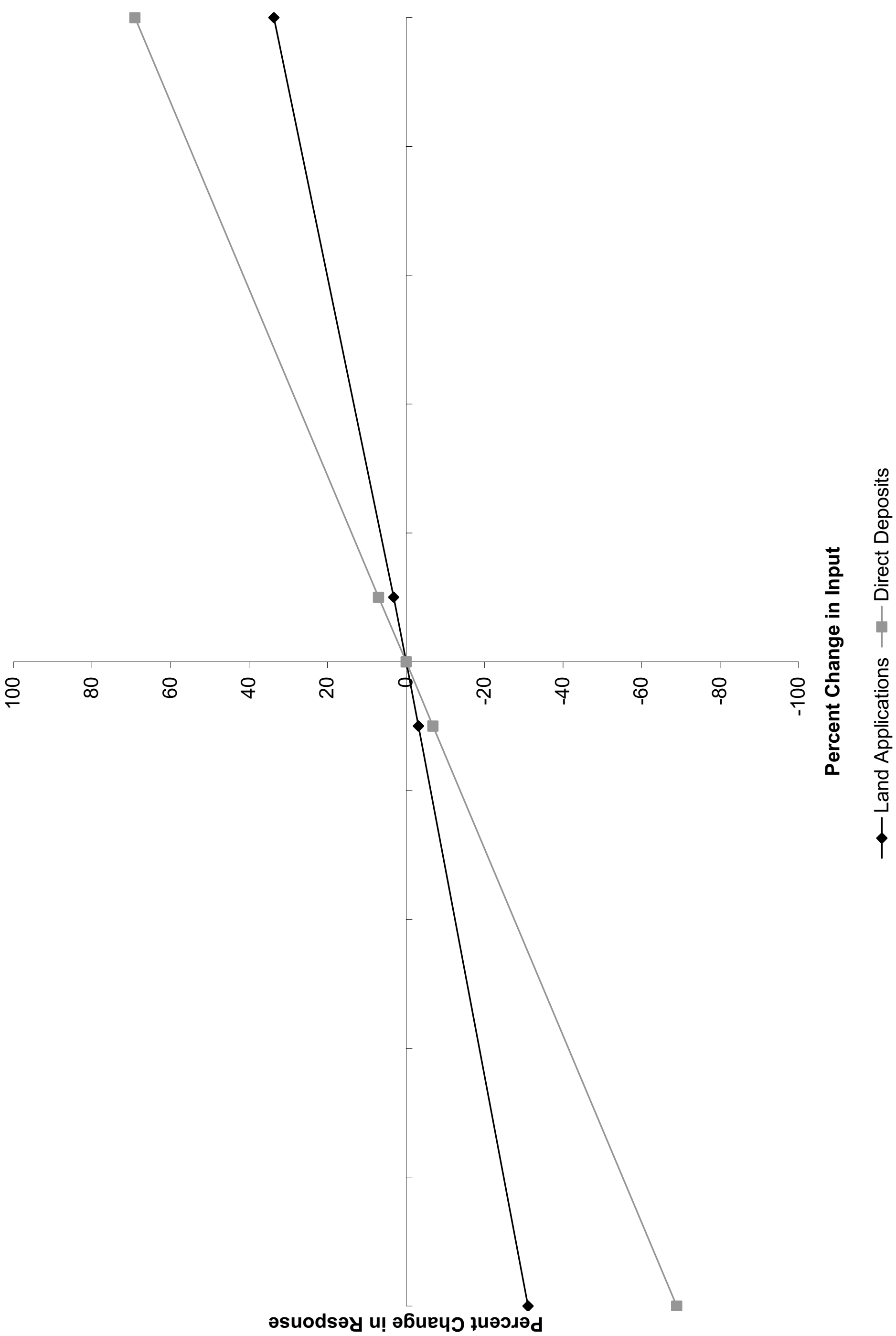

Figure 4.10 Total loading sensitivity to changes in direct and land-based loads for the Straight Creek watershed.

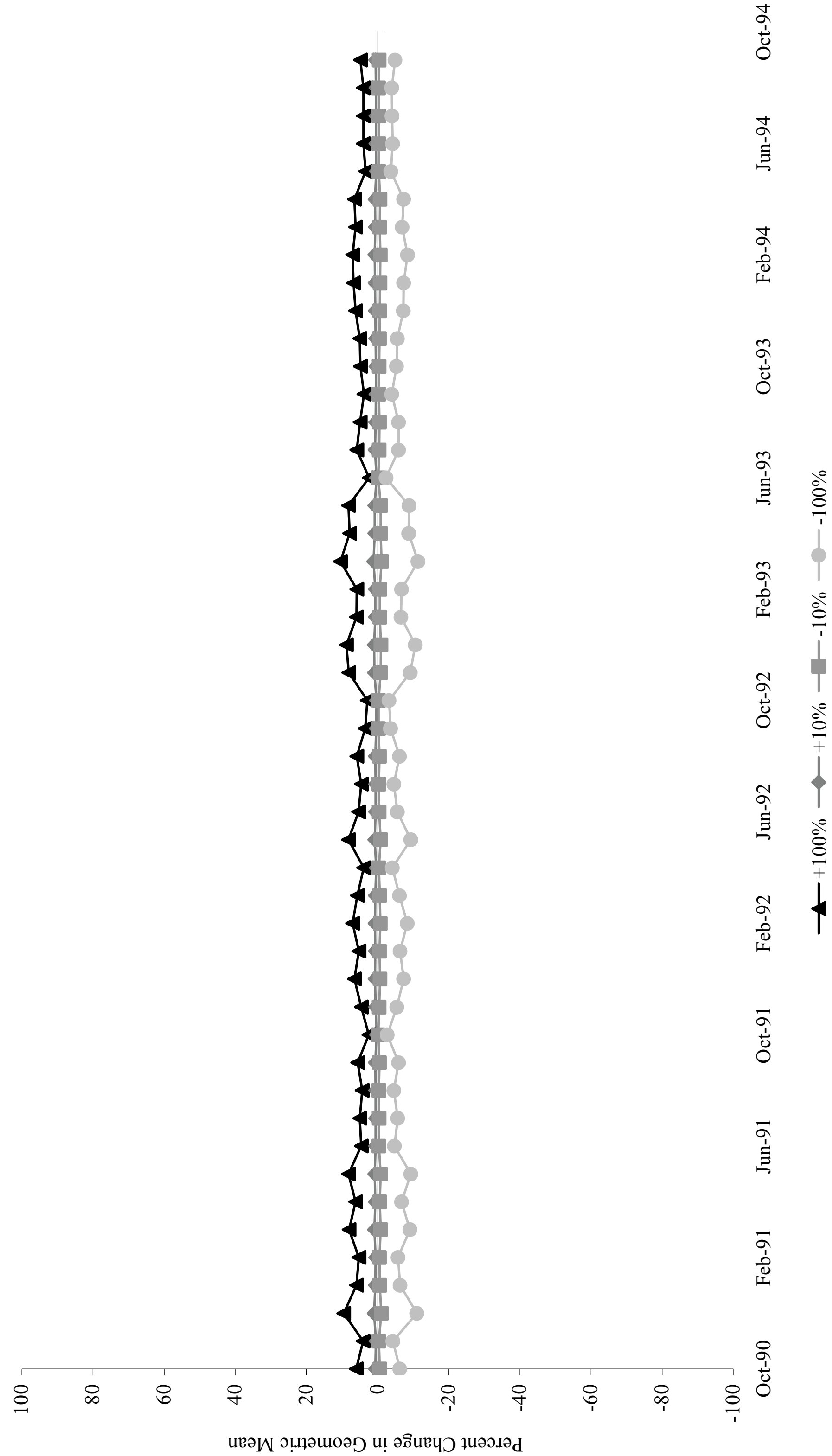

Figure 4.11 Results of sensitivity analysis on monthly geometric-mean concentrations in the Straight Creek watershed, as affected by changes in land-based loadings.

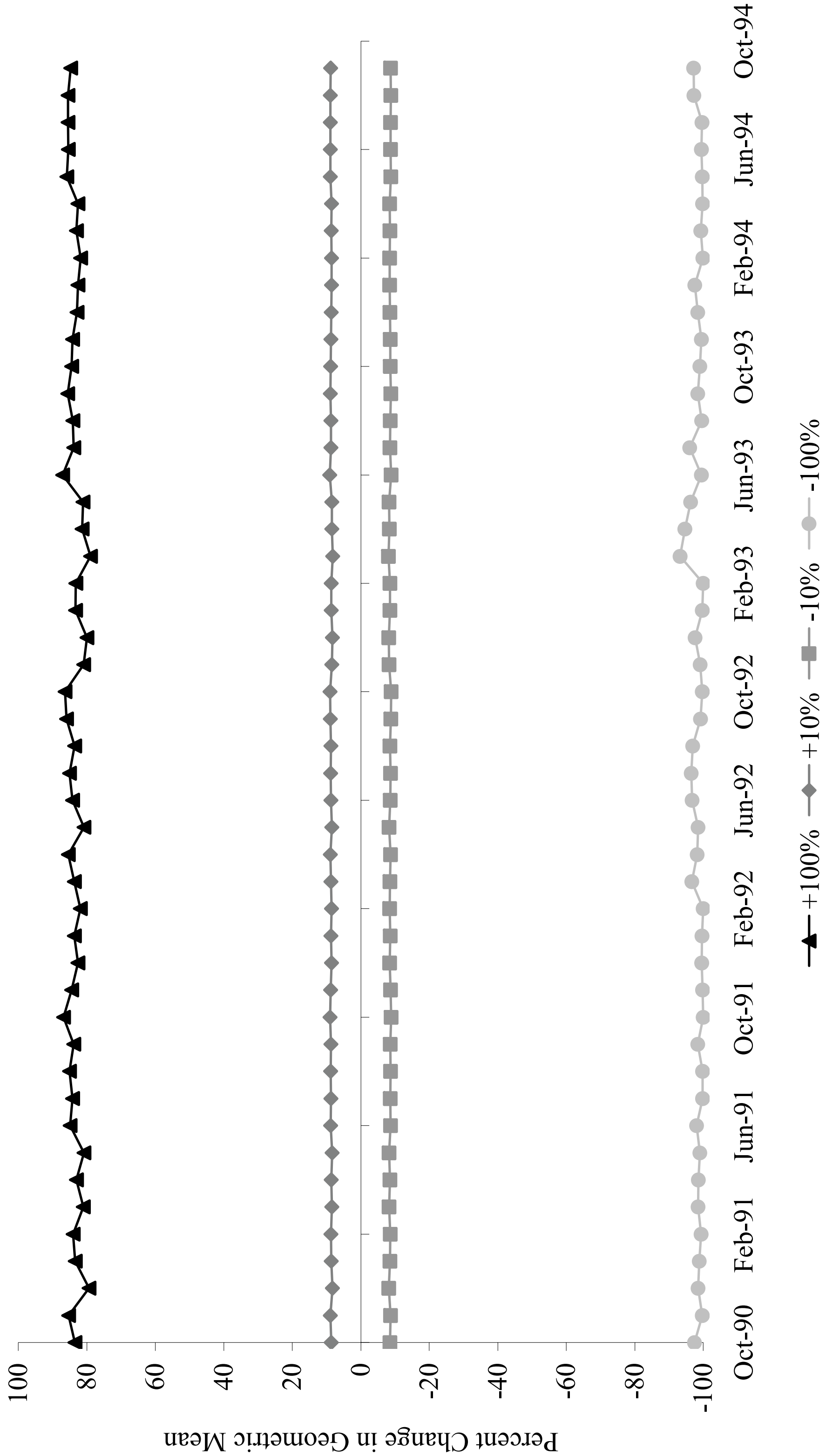

Figure 4.12 Results of sensitivity analysis on monthly geometric-mean concentrations in the Straight Creek watershed, as affected by changes in loadings from direct nonpoint sources.

4.7 Model Calibration Process

Calibration is performed in order to ensure that the model accurately represents the hydrologic and water quality processes in the watershed. The model's hydrologic parameters were set based on available soils, land use, and topographic data. Through calibration, these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable. Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Using observed data that is reported at a shorter time-step improves this process and subsequently the performance of a time-dependent model.

4.7.1 Hydrologic Calibration

Parameters that were adjusted during the hydrologic calibration represented the amount of evapotranspiration from the root zone (MON-LZETP), the recession rates for groundwater (AGWRC), the amount of soil moisture storage in the upper zone (MON-UZSN) and lower zone (MON-LZSN), the infiltration capacity (INFILT), baseflow PET (potential evapotranspiration) (BASETP), direct ET from shallow groundwater (AGWETP), and Manning's *n* for overland flow plane (MON-MAN). Although HSPF is not a physically based model, and thus parameters are adjusted during calibration in order to match observed data, guidelines are provided by the EPA as to typically encountered values.

The Straight Creek model was initially calibrated for hydrologic accuracy using continuous stream flow data at USGS Station #03530500 on the North Fork Powell River (subwatershed 5). The results of hydrology calibration for the North Fork Powell River are presented in Table 4.10 and Figures 4.12 through Figure 4.14. Table 4.10 shows the percent difference (or error) between observed and modeled data for total in-stream flows, -9.62%, upper 10% flows, -9.60%, and lower 50% flows, 8.33% during model calibration.

Table 4.10 Hydrology calibration criteria and model performance for the North Fork Powell River at the outlet of subwatershed 5 for the period 10/01/1991 through 3/31/1995.

Criterion	Observed	Modeled	Error
Total In-stream Flow:	106.71	96.44	-9.62%
Upper 10% Flow Values:	58.70	53.07	-9.60%
Lower 50% Flow Values:	9.15	9.91	8.33%
Winter Flow Volume	58.18	43.78	-24.75%
Spring Flow Volume	18.36	20.55	11.96%
Summer Flow Volume	4.82	5.20	7.86%
Fall Flow Volume	25.34	26.91	6.16%
Total Storm Volume	100.70	86.17	-14.43%
Winter Storm Volume	56.48	40.87	-27.63%
Spring Storm Volume	17.07	18.35	7.52%
Summer Storm Volume	3.53	3.01	-14.96%
Fall Storm Volume	23.61	23.94	1.39%

MapTech received additional data from Biological Monitoring Inc. (BMI) on January 10, 2005. The data consisted of flow measurements recorded by BMI at seven locations on Straight Creek and tributaries from 11/8/2004 to 12/30/2004. There was not enough data to extrapolate an entire year of data to use in hydrology calibration. This data was used qualitatively to ensure that the hydrologic model was accurate. The Straight Creek hydrologic model produced flow values within the min and max of the observed flow measured by BMI.

All final calibrated parameters were within the typical values (Table 4.11). The distribution of flow volume between groundwater interflow, surface runoff was 50%, 32%, and 18%, respectively.

Table 4.11 Model parameters utilized for hydrologic calibration of the Straight Creek and North Fork Powell River watersheds.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
FOREST	---	0.0 – 0.95	1.0	1.0
LZSN	in	2.0 – 15.0	0.108 – 11.041	2.0
INFILT	in/hr	0.001 – 0.50	0.001 – 0.3845	0.001 – 0.1154
LSUR	ft	100 – 700	7.12 – 782.8	7.12 – 615.09
SLSUR	---	0.001 – 0.30	0.0315 – 0.3537	0.0315 – 0.30
KVARY	1/in	0.0 – 5.0	0.0	0.0
AGWRC	1/day	0.85 – 0.999	0.980	0.945 – 0.980
PETMAX	deg F	32.0 – 48.0	40.0	40.0
PETMIN	deg F	30.0 – 40.0	35.0	35.0
INFEXP	---	1.0 – 3.0	2.0	2.0
INFILD	---	1.0 – 3.0	2.0	2.0
DEEPFR	---	0.0 – 0.50	0.010	0.0 – 0.5
BASETP	---	0.0 – 0.20	0.010	0.035
AGWETP	---	0.0 – 0.20	0.0	0.0 – 0.2
INTFW	---	1.0 – 10.0	1.0	1.0 – 1.3
IRC	1/day	0.30 – 0.85	0.5	0.5 – 0.6
MON-INTERCEP	in	0.01 - 0.40	0.01 – 0.2	0.01 – 0.2
MON-UZSN	in	0.05 – 2.0	0.05 – 9.952	0.05 – 2.0
MON-LZETP	---	0.10 – 0.90	0.01 – 0.8	0.1 – 0.17
MON-MANNING	---	0.05 – 0.50	0.1	0.05
RETSC	in	0.01 – 0.30	0.1	0.1
KS	---	0.0 – 0.99	0.5	0.5

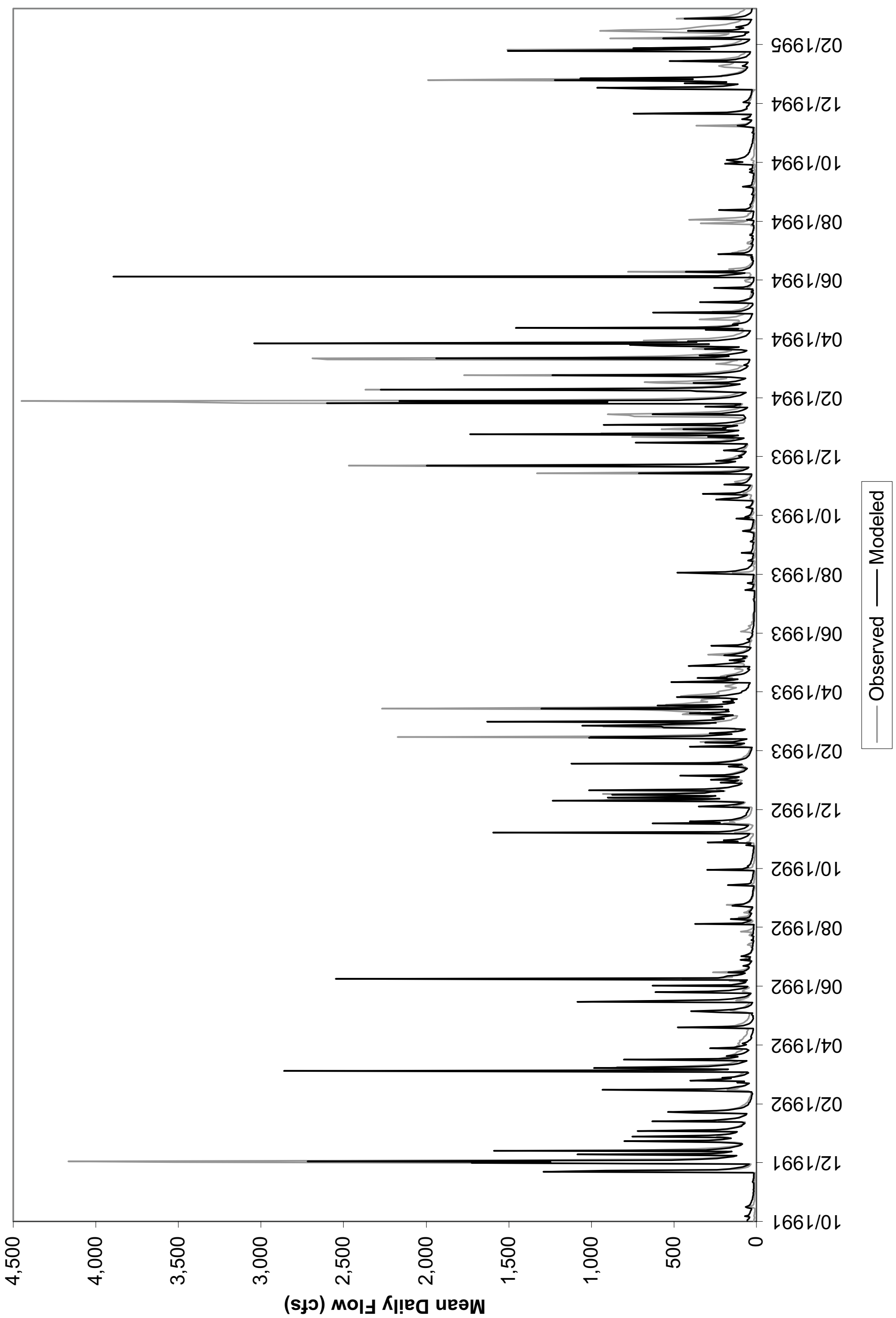

Figure 4.13 Hydrology calibration results for the North Fork Powell River at subwatershed 5 (10/01/1991 through 3/31/1995).

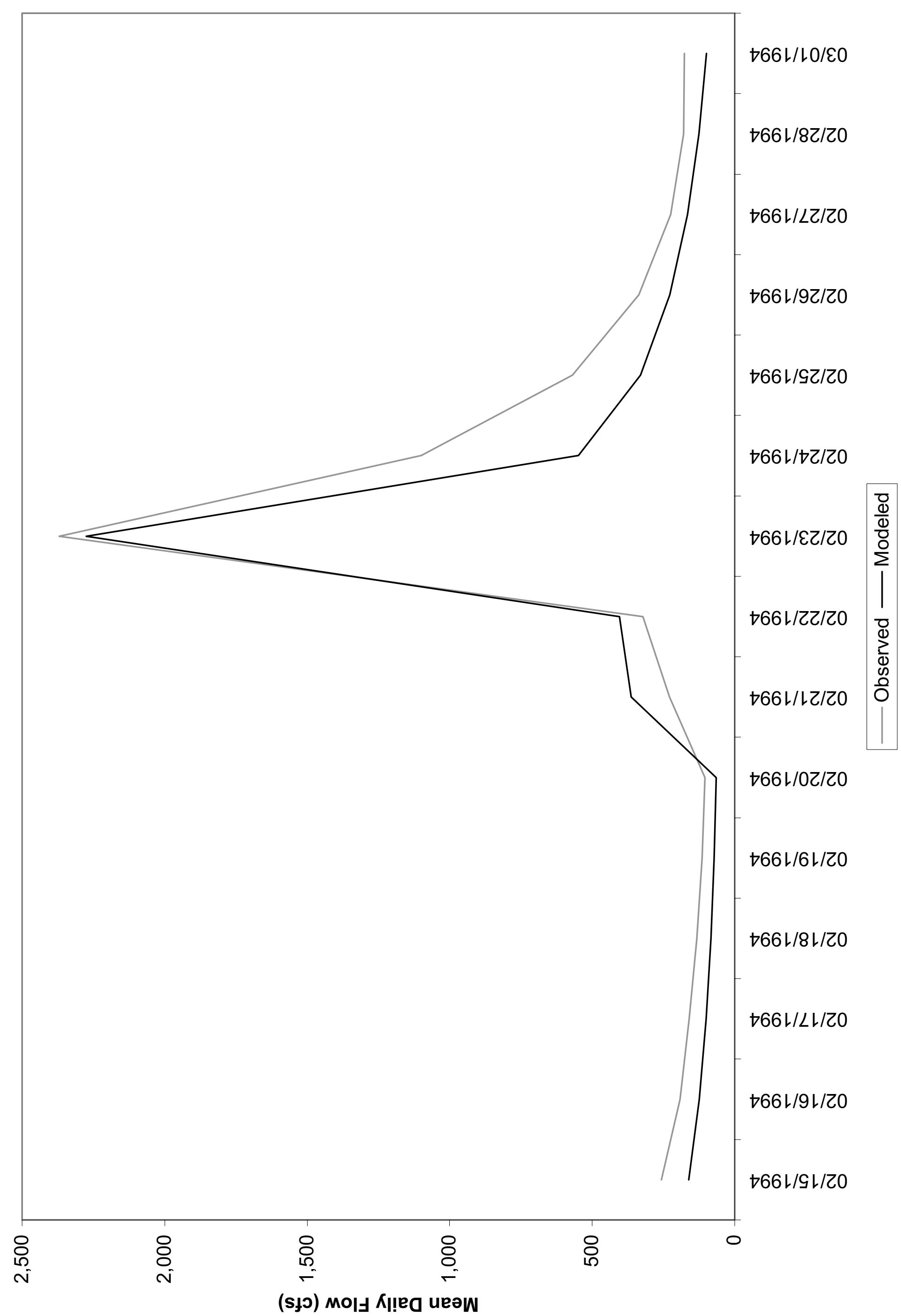

Figure 4.14 Hydrology calibration results for a single storm for the North Fork Powell River at subwatershed 5 (02/15/1994– 03/01/1994).

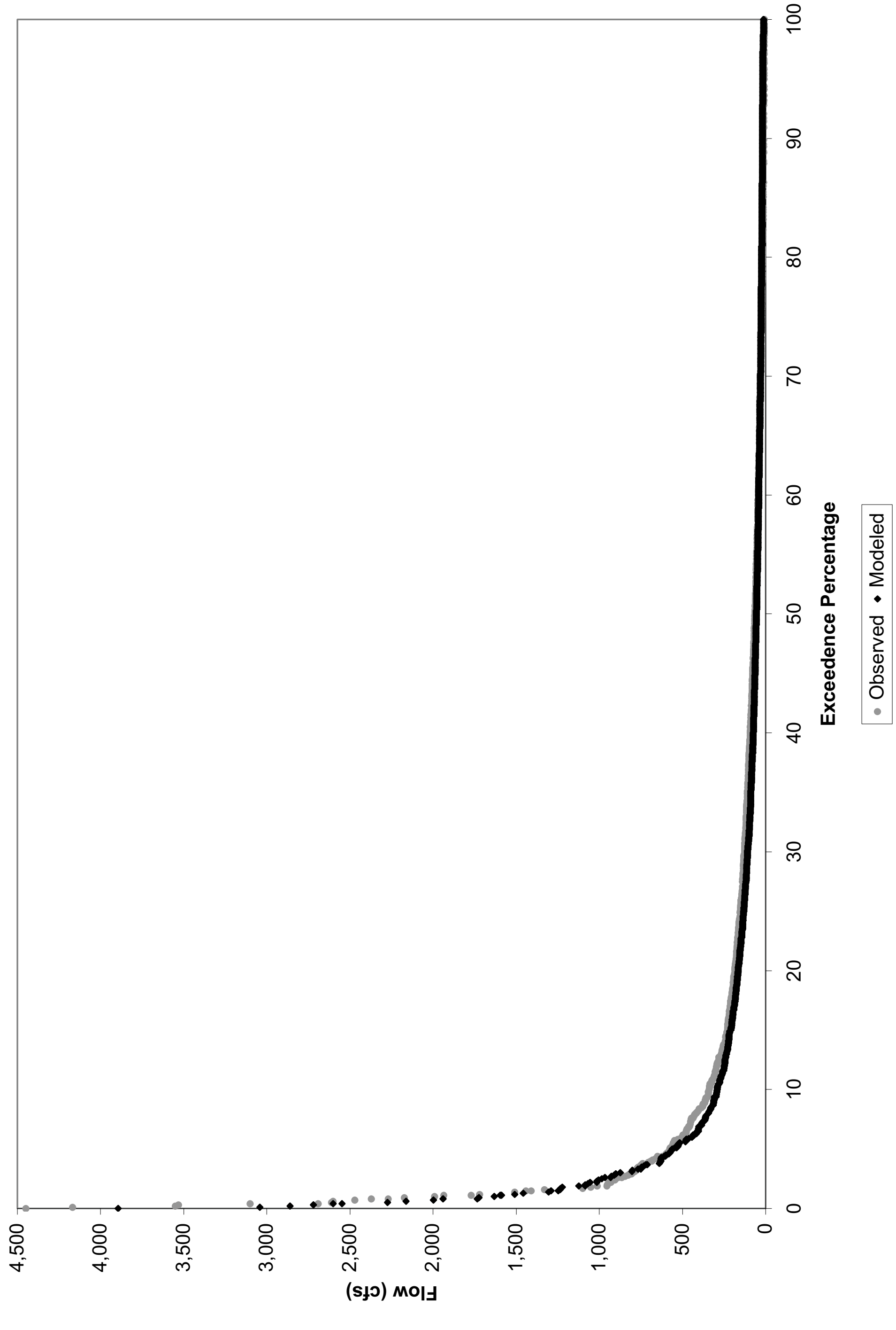

Figure 4.15 North Fork Powell River flow duration at subwatershed 5 (10/01/1991 through 3/31/1995).

4.7.2 Water Quality Calibration

Water quality calibration is complicated by a number of factors, some of which are described here. First, water quality concentrations (*e.g.*, fecal coliform concentrations) are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters such as fecal coliform concentration. Second, the concentration of fecal coliform is particularly variable. Variability in location and timing of fecal deposition, variability in the density of fecal coliform bacteria in feces (among species and for an individual animal), environmental impacts on regrowth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling fecal coliform concentrations. Additionally, the limited amount of measured data for use in calibration and the practice of censoring both high (typically 8,000 or 16,000 cfu/100 mL) and low (typically under 100 cfu/100 mL) concentrations impede the calibration process.

Three parameters were utilized for model adjustment: in-stream first-order decay rate (FSTDEC), maximum accumulation on land (SQOLIM), and rate of surface runoff that will remove 90% of stored fecal coliform per hour (WSQOP). All of these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled fecal coliform concentrations was established.

The Straight Creek fecal coliform water quality model was calibrated against observed values from 10/1/1990 to 9/29/1994. Table 4.12 shows the results of fecal coliform calibration for Straight Creek. All parameters used in the calibration were within typical ranges (the PERLND Water had a WSQOP value of 0.0). Figure 4.15 shows the modeled daily average fecal coliform concentration versus observed data in Straight Creek. As the fecal coliform sensitivity analysis shows, the model is driven by direct deposition. Direct deposits cause in-stream fecal coliform concentrations to spike and fall rapidly during a day. Figure 4.15 is a graph of the average daily fecal coliform concentration; the model was also evaluated on the daily minimum and maximum to account for the variations during the day. The model was calibrated to include the monitored values in the daily maximum and minimum.

Table 4.12 Model parameters utilized for fecal coliform water quality calibration of the Straight Creek watershed.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
MON-ACCUM	FC/ac*day	0.0 – 1.0E+20	0.0 – 1.6E+10	0.0 – 1.6E+10
MON-SQOLIM	FC/ac	0.01 – 1.0E+30	0.0 – 1.6E+10	0.0 – 3.2E+11
WSQOP	in/hr	0.05 – 3.00	0.0 – 2.8	0.0 – 1.4
IOQC	FC/ft^3	0.0 – 1.0E+06	0.0	0.0
AOQC	FC/ft^3	0 – 10	0.0	0.0
DQAL	FC/100mL	0 – 1,000	200	200
FSTDEC	1/day	0.01 – 10.00	1.0	0.8
THFST	---	1.0 – 2.0	1.07	1.07

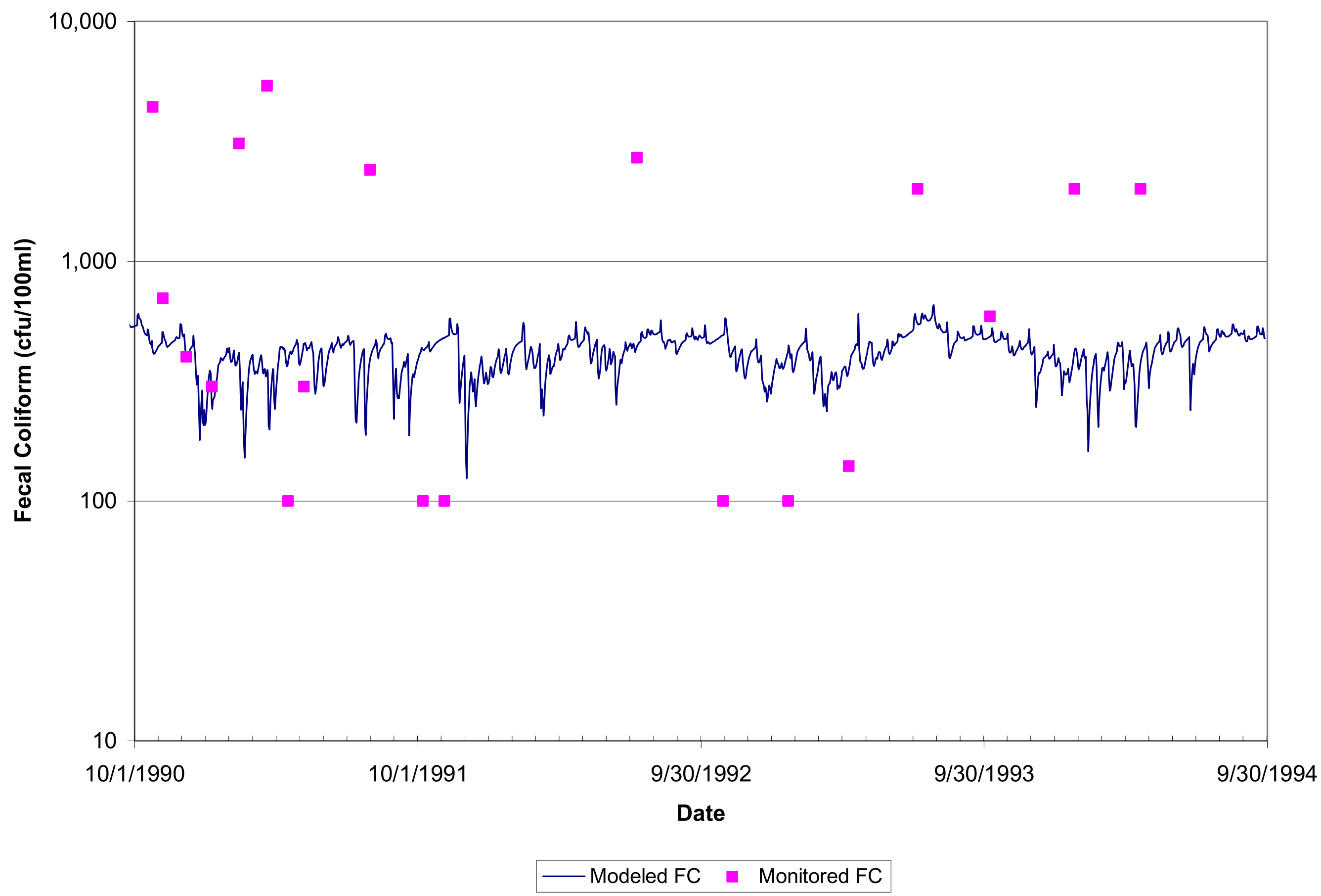

Figure 4.16 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations in the Straight Creek impairment at 6BSRA001.11 during calibration.

4.7.2.1 Water Quality Calibration Statistics

Careful inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. To provide a quantitative measure of the agreement between modeled and measured data while taking the inherent variability of fecal coliform concentrations into account, each observed value was compared with modeled concentrations in a 2-day window surrounding the observed data point. Standard error in each observation window was calculated as follows:

$$Standard\ Error = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}\left(observed - modeled_i\right)^2}{(n-1)}}}{\sqrt{n}}$$

where

$$\begin{aligned} observed &= \text{an observed value of fecal coliform} \\ modeled_i &= \text{a modeled value in the 2-day window surrounding the observation} \\ n &= \text{the number of modeled observations in the 2-day window} \end{aligned}$$

This is a non-traditional use of standard error, applied here to offer a quantitative measure of model accuracy. In this context, standard error measures the variability of the sample mean of the modeled values about an instantaneous observed value. The use of limited instantaneous observed values to evaluate continuous data introduces error and, therefore, increases standard error. The mean of all standard errors for each station analyzed was calculated. Additionally, the maximum concentration values observed in the simulated data were compared with maximum values obtained from uncensored data and found to be at reasonable levels (Tables 4.13).

The standard error in the Straight Creek model was 128.0 (Table 4.13). The high standard error values can be considered quite reasonable when one takes into account the censoring of maximum values that is practiced in the taking of actual water quality samples. The standard error will be biased upwards when an observed high value censored at 8,000 cfu is compared to a simulated high value that may be an order of magnitude or more above the censor limit. Considering the data in Table 4.13, it is evident that the higher standard errors coincide with the higher simulated maximum values as expected. Thus, the standard errors calculated for these impairments are considered an indicator of strong model performance.

Table 4.13 Results of analyses on fecal coliform calibration for Straight Creek.

Station	Mean Standard Error (cfu/100 mL)	Maximum Simulated Value (cfu/100 mL)	Simulated FC Instantaneous Violations (%)	Monitored FC Instantaneous Violations (%)
6BSRA001.11	128	737	62.7	57.9

4.8 Existing Loadings

All appropriate inputs were updated to 2004 conditions. All model runs were conducted using precipitation data during hydrologic calibration. Figure 4.16 shows the monthly geometric mean of *E. coli* concentrations in relation to the 126-cfu/100mL standard for Straight Creek. Figure 4.17 shows the instantaneous values of *E. coli* concentrations in relation to the 235-cfu/100 mL standard for Straight Creek. These figures show that there are violations of both standards at the impairment outlet during the calibration periods. Appendix B contains tables with monthly loadings to the different land use areas in each subwatershed.

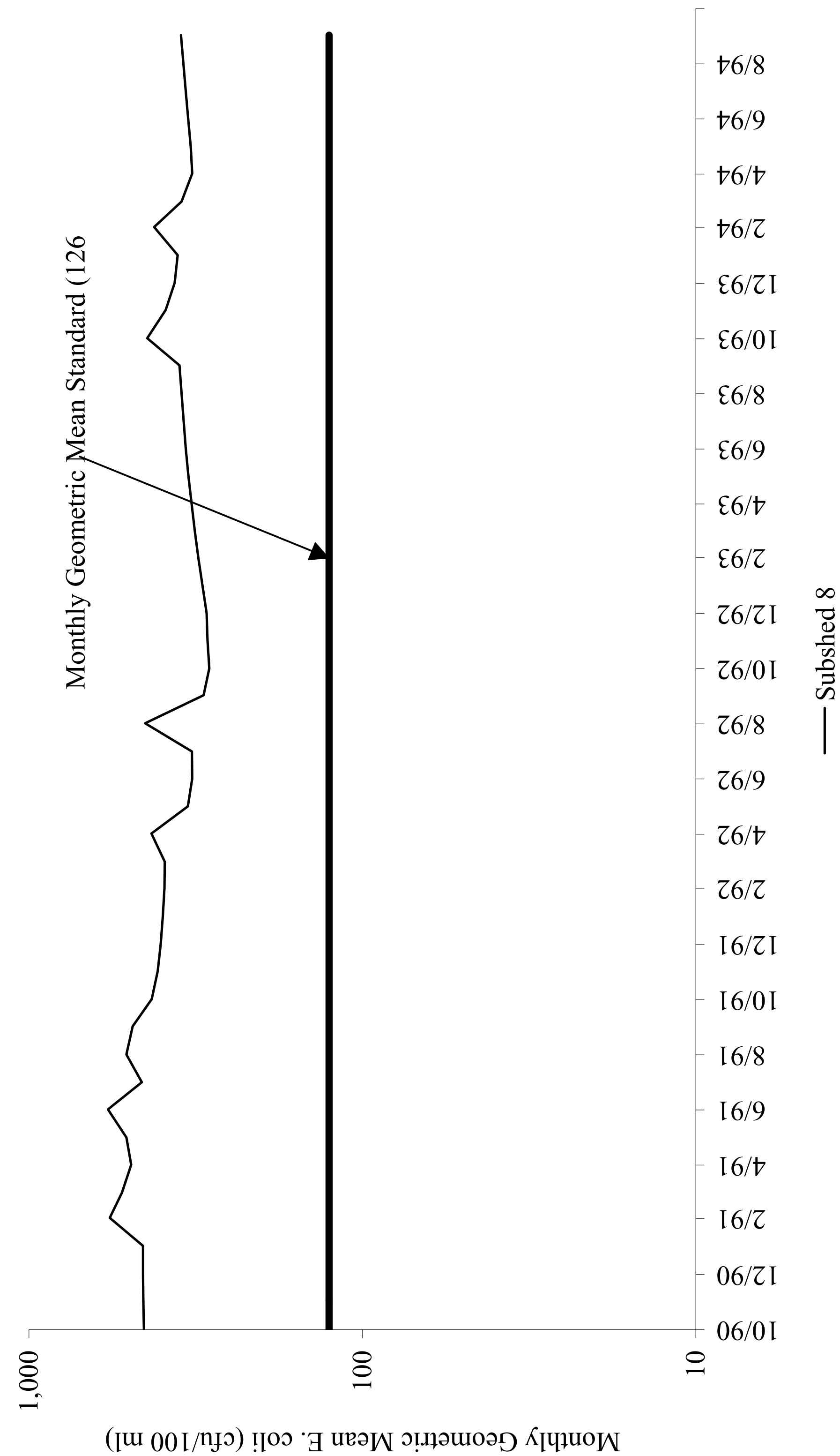

Figure 4.17 Existing conditions (*i.e.*, monthly geometric-mean) of *E. coli* concentrations at the outlet of the Straight Creek impairment (subwatershed 8+9).

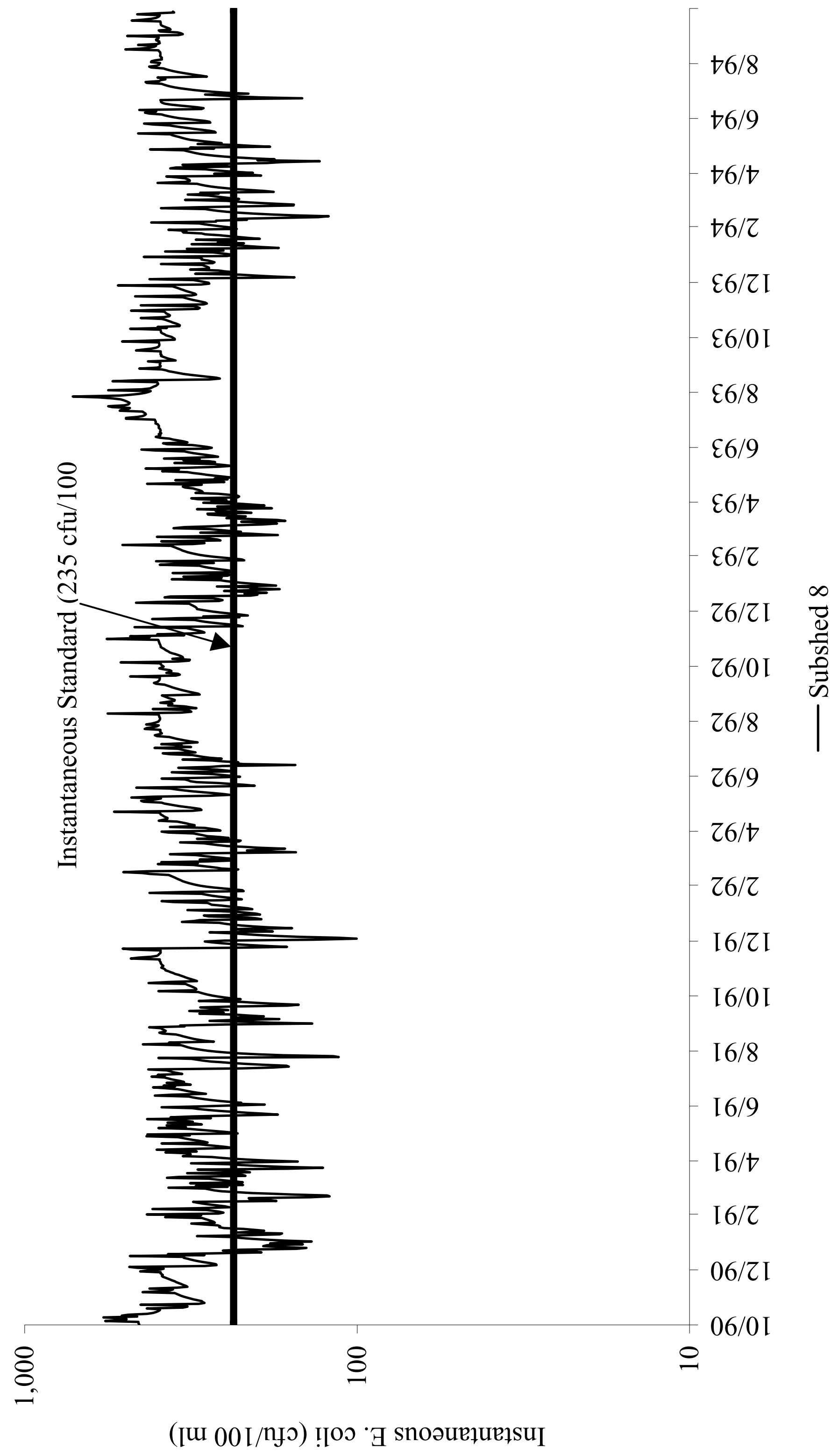

Figure 4.18 Existing conditions (*i.e.*, mean daily) of *E. coli* concentrations at the outlet of the Straight Creek impairment (subwatershed 8+9).

5. ALLOCATION

TMDLs consist of waste load allocations (WLAs, permitted sources) and load allocations (LAs, nonpoint/non-permitted sources) including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainties in the process (*e.g.,* accuracy of wildlife populations). The definition is typically denoted by the expression:

$$TMDL = WLAs + LAs + MOS$$

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving waterbody and still achieve water quality standards. For fecal bacteria, TMDL is expressed in terms of colony forming units (or resulting concentration).

5.1 Incorporation of a Margin of Safety

In order to account for uncertainty in modeled output, an MOS was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. A margin of safety can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. The intention of a MOS in the development of a fecal coliform TMDL is to ensure that the modeled loads do not under-estimate the actual loadings that exist in the watershed. An implicit MOS was used in the development of this TMDL. By adopting an implicit MOS in estimating the loads in the watershed, it is insured that the recommended reductions will, in fact, succeed in meeting the water quality standard. Examples of implicit MOS used in the development of this TMDL were:

- Allocating permitted point sources at the maximum allowable fecal coliform concentration
- The selection of a modeling period that represented the critical hydrologic conditions in the watershed

5.2 Scenario Development

Allocation scenarios were modeled using HSPF. Existing conditions were adjusted until the water quality standard was attained. The TMDL developed for the Straight Creek watershed was based on the Virginia State Standard for *E. coli*. As detailed in Section 2.1, the *E. coli* standard states that the calendar month geometric-mean concentration shall not exceed 126 cfu/100 mL, and that a maximum single sample concentration of *E. coli* not exceed 235 cfu/100 mL. According to the guidelines put forth by VADEQ (VADEQ, 2003) for modeling *E. coli* with HSPF, the model was set up to estimate loads of fecal coliform, then the model output was converted to concentrations of *E. coli* through the use of the following equation (developed from a dataset containing n-493 paired data points):

$$\log_2(C_{ec}) = -0.0172 + 0.91905 \cdot \log_2(C_{fc})$$

Where C_{ec} is the concentration of *E. coli* in cfu/100 mL, and C_{fc} is the concentration of fecal coliform in cfu/100 mL.

Pollutant concentrations were modeled over the entire duration of a representative modeling period, and pollutant loads were adjusted until the standard was met. The development of the allocation scenario was an iterative process that required numerous runs with each run followed by an assessment of source reduction against the water quality target.

5.2.1 Wasteload Allocations

There is one non-mining point sources currently permitted to discharge in the Straight Creek watershed (Figure 3.2 and Table 3.2). This permitted discharge is not permitted for fecal control. For water quality modeling this discharge was modeled at its design flow with zero cfu/100mL of fecal coliform.

5.2.2 Load Allocations

Load allocations to nonpoint sources are divided into land-based loadings from land uses and directly applied loads in the stream (*e.g.,* livestock, and wildlife). Source reductions include those that are affected by both high and low flow conditions. Land-based NPS loads had their most significant impact during high-flow conditions, while direct deposition NPS had their most significant impact on low flow concentrations. Bacterial source tracking during 2003-2004 sampling periods confirmed the presence of human, pet, livestock and wildlife contamination.

Model results indicate that human direct deposits, and urban and agricultural nonpoint sources are significant in all areas of the watershed. This is in agreement with the results of BST analysis presented in Chapter 2. Allocation scenarios for Straight Creek are shown in Table 5.1. Scenario 1 describes a baseline scenario that corresponds to the existing conditions in the watershed.

The first objective of reduction scenarios was to explore the role of anthropogenic sources in standards violations. First, scenarios were explored to determine the feasibility of meeting standards without wildlife reductions. Following this theme, Scenario 2 resulted from 100% reductions in uncontrolled residential discharges (*i.e.,* straight pipes). This scenario greatly improved conditions in the stream, but failed to eliminate exceedances.

Scenario 3 had a 90% reduction in direct livestock deposition, and 50% reductions to land loads from urban and agricultural lands, as well as a 100% reduction of straight pipes. Direct loads from wildlife were not addressed. Again while it showed improved conditions, it still did not meet the instantaneous standard.

Scenario 4 shows 100% reductions to anthropogenic sources; however, exceedances still persisted with the instantaneous standard. This scenario shows that reductions to wildlife loads must be made.

Scenarios 5 and 6 had fewer reductions to agricultural and urban nonpoint source loads to provide more obtainable scenarios. Scenario 5 shows that reductions in direct wildlife loads had little impact on the percent violations; however, Scenario 6 shows that the same percent reduction in land-based wildlife loads lowered the instantaneous violations. This shows that reductions in land-based wildlife loads were necessary to lower the violation percentage whereas reductions in direct wildlife loads are not required.

Additional scenarios were made by iteratively reducing nonpoint source wildlife loads until a scenario was found that resulted in zero exceedances of both standards (Scenario 7, Table 5.1). Next, the scenario with the least reductions was found by decreasing the reductions of direct livestock, nonpoint agricultural and urban loads while maintaining zero percent violations of both standards (Scenario 8, Table 5.1).

Table 5.1 Allocation scenarios for bacterial concentration with current loading estimates in the Straight Creek impairment.

Scenario Number	Percent Reduction in Loading from Existing Condition						Percent Violations	
	Direct Wildlife	NPS Wildlife	Direct Livestock	NPS Pasture/ Livestock	NPS Residential/ Urban	Straight Pipes	GM >126 cfu/ 100mL	Single Sample >235 cfu/ 100mL
1	0	0	0	0	0	0	100.0	84.29
2	0	0	0	0	0	100	0.0	2.19
3	0	0	90	50	50	100	0.0	1.44
4	0	0	100	100	100	100	0.0	0.82
5	10	0	100	99	99	100	0.0	0.82
6	0	10	100	99	99	100	0.0	0.55
7	0	32	100	99	99	100	0.0	0.0
8	0	32	0	80	99	100	0.0	0.0

5.2.2.1 Final bacteria TMDL

Figure 5.1 shows graphically the existing and allocated conditions for the geometric-mean *E. coli* concentrations in Straight Creek. Figure 5.2 shows the existing and allocated conditions of the instantaneous *E. coli* concentration in Straight Creek. The figures for Straight Creek are for the *E. coli* concentrations at the outlet (subwatershed 8).

Table 5.2 indicates the land-based and direct load reductions resulting from the final allocations. Table 5.3 shows the final TMDL loads for the Straight Creek impairment.

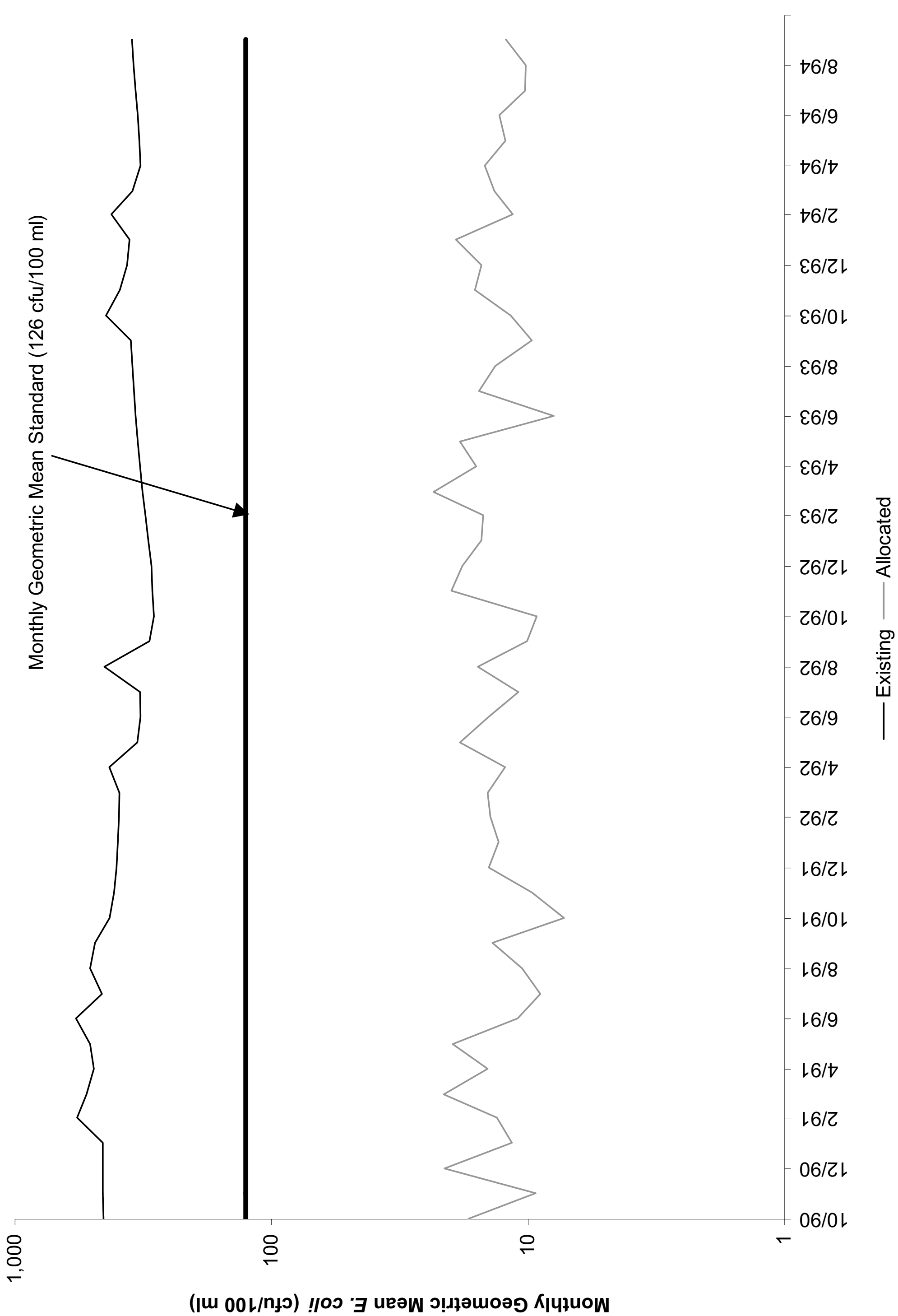

Figure 5.1 Monthly geometric mean *E. coli* concentrations for Straight Creek at the outlet under existing and allocated conditions.

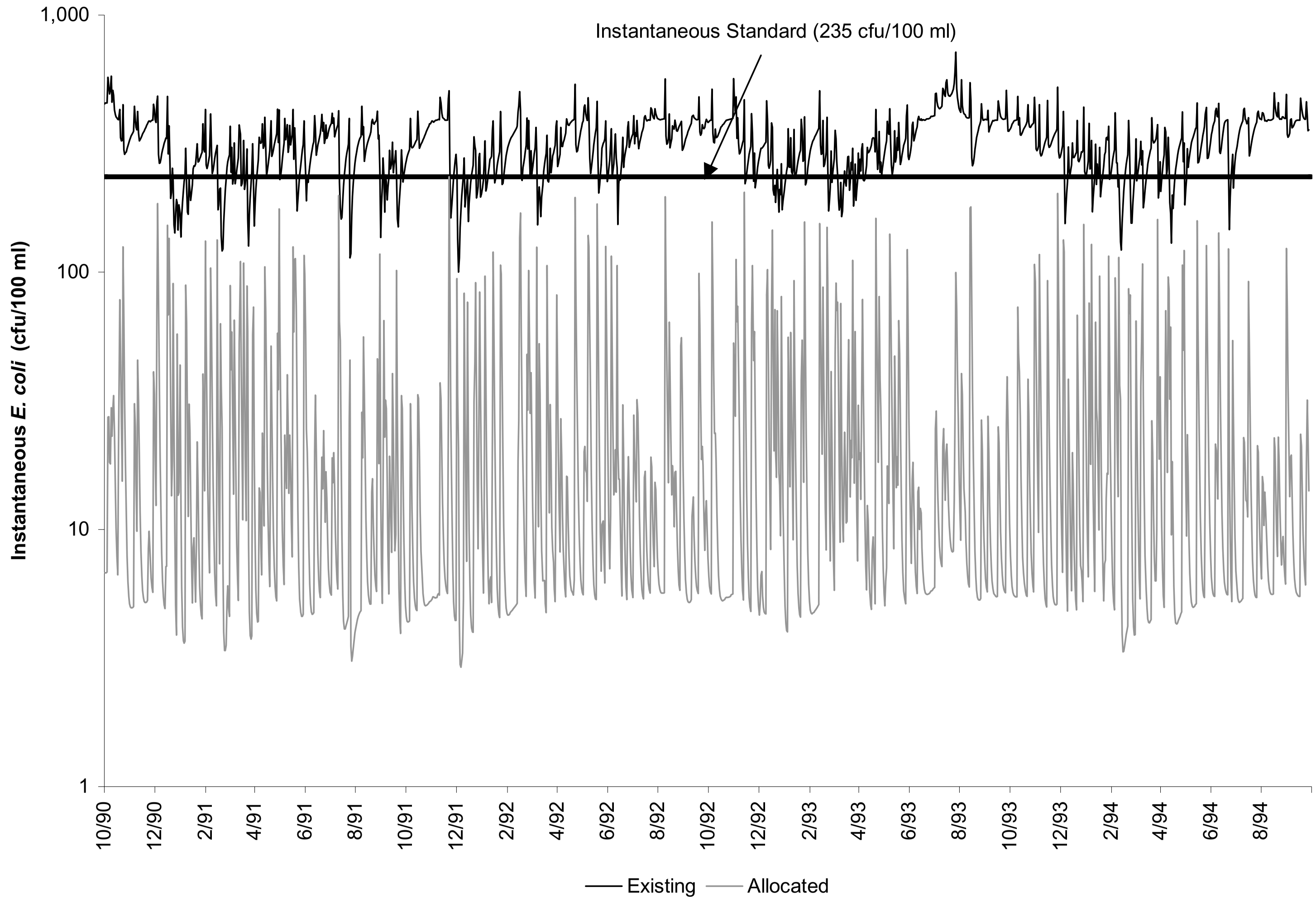

Figure 5.2 Instantaneous *E. coli* concentrations for Straight Creek at the outlet under existing and allocated conditions.

Table 5.2 Land-based and direct *E. coli* loads in the Straight Creek impairment for existing conditions and the final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Abandoned Mine Land	3.11E+13	2.11E+13	32%
Active Mining	6.07E+12	6.07E+10	99%
Barren	5.64E+10	5.64E+08	99%
Commercial	8.69E+11	8.69E+09	99%
Cropland	2.32E+11	4.64E+10	80%
Forest	2.24E+14	1.52E+14	32%
Livestock Access	3.33E+11	6.66E+10	80%
Pasture	7.57E+12	1.51E+12	80%
Reclaimed	4.38E+13	2.98E+13	32%
Residential	6.60E+13	6.60E+11	99%
Roads	4.66E+12	4.66E+10	99%
Water	0.00E+00	0.00E+00	0%
Wetland	2.46E+11	1.67E+11	32%
Direct			
Livestock	3.55E+10	3.55E+10	0%
Wildlife	5.70E+12	5.70E+12	0%
Straight Pipes	4.96E+14	0.00E+00	100%

Table 5.3 Average annual *E. coli* loads (cfu/year) modeled after allocation in the Straight Creek watershed.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Straight Creek (FC)	0.00E+00	1.81E+13	*Implicit*	1.81E+13

This page intentionally left blank

PART III: GENERAL STANDARD (BENTHIC) TMDLS

This page intentionally left blank

6. WATER QUALITY ASSESSMENT

6.1 Applicable Criterion for Benthic Impairment

The General Standard, as defined in Virginia state law 9 VAC 25-260-20, states:

> *A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.*

The General Standard is implemented by VADEQ through application of the modified Rapid Bioassessment Protocol II (RBP II). Using the modified RBP II, the health of the benthic macroinvertebrate community is typically assessed through measurement of 8 biometrics (Table 6.1), which measure different aspects of the community's overall health. Surveys of the benthic macroinvertebrate community performed by VADEQ are assessed at the family taxonomic level (Barbour, 1999).

Each biometric measured at a target station is compared to the same biometric measured at a reference (not impaired) station to determine each biometric score. These scores are then summed and used to determine the overall bioassessment (*e.g.,* not impaired, slightly impaired, moderately impaired, or severely impaired).

Table 6.1 Components of the modified RBP II Assessment.

Biometric	Benthic Health [1]
Taxa Richness	↑
Modified Family Biotic Index (MFBI)	↓
Scraper to Filtering Collector Ratio (SC/CF)	↑
EPT / Chironomid Ratio (EPT/CHI ABUND)	↑
% Contribution of Dominant Family (% DOM)	↓
EPT Index	↑
Community Loss Index (COMM. LOSS INDEX)	↓
Shredder to Total Ratio (SH/TOT)	↑

[1] An upward arrow indicates a positive response in benthic health when the associated biometric increases.

6.2 Benthic Assessment

All biological and ambient water quality monitoring stations on Straight Creek are shown in Table 6.2 and Figure 6.1. Modified RBP II benthic surveys were performed by VADEQ on four sites on Straight Creek. Table 6.2 relates the station number to the station type and river mile location. The results of these surveys are presented in Tables 6.3, 6.4 and 6.5. The tables indicate that the majority of the surveys found moderately impaired conditions. The primary difference between Straight Creek and the reference stations was the absence of pollution sensitive organisms such as mayflies, stoneflies and caddisflies.

Table 6.2 Benthic and ambient monitoring stations on Straight Creek.

Station	Station Type[1]	River Mile
6BSRA000.10	VADEQ Ambient	0.10
6BSRA000.11	VADEQ Bio	0.11
SC	ECI_Ambient,Bio	0.19
6BSRA000.40	VADEQ _Bio	0.40
6BSRA000.54	VADEQ SS	0.54
6BSRA001.10	VADEQ SS	1.10
6BSRA001.11	VADEQ Ambient	1.11
6BSRA001.34	VADEQ _FT	1.34
0003102*	DMME monitoring site	2.12
SB	ECI_Ambient,Bio	2.40
6BSRA002.48	VADEQ Bio	2.48
6BSRA003.22	VADEQ Ambient	3.22
1020127	DMME monitoring site	3.26
6BSRA003.62	VADEQ Bio	3.62
SA	ECI_Ambient,Bio	3.84
0002877	DMME monitoring site	4.87
1020209	DMME monitoring site	5.32
1020237	DMME monitoring site	5.37
1020241	DMME monitoring site	5.57
1020226	DMME monitoring site	5.64
1020225	DMME monitoring site	6.06

[1]Bio: Biological, SS: Special study, Ambient: Ambient water quality, FT: Fish Tissue
*Station with less than nine data points.

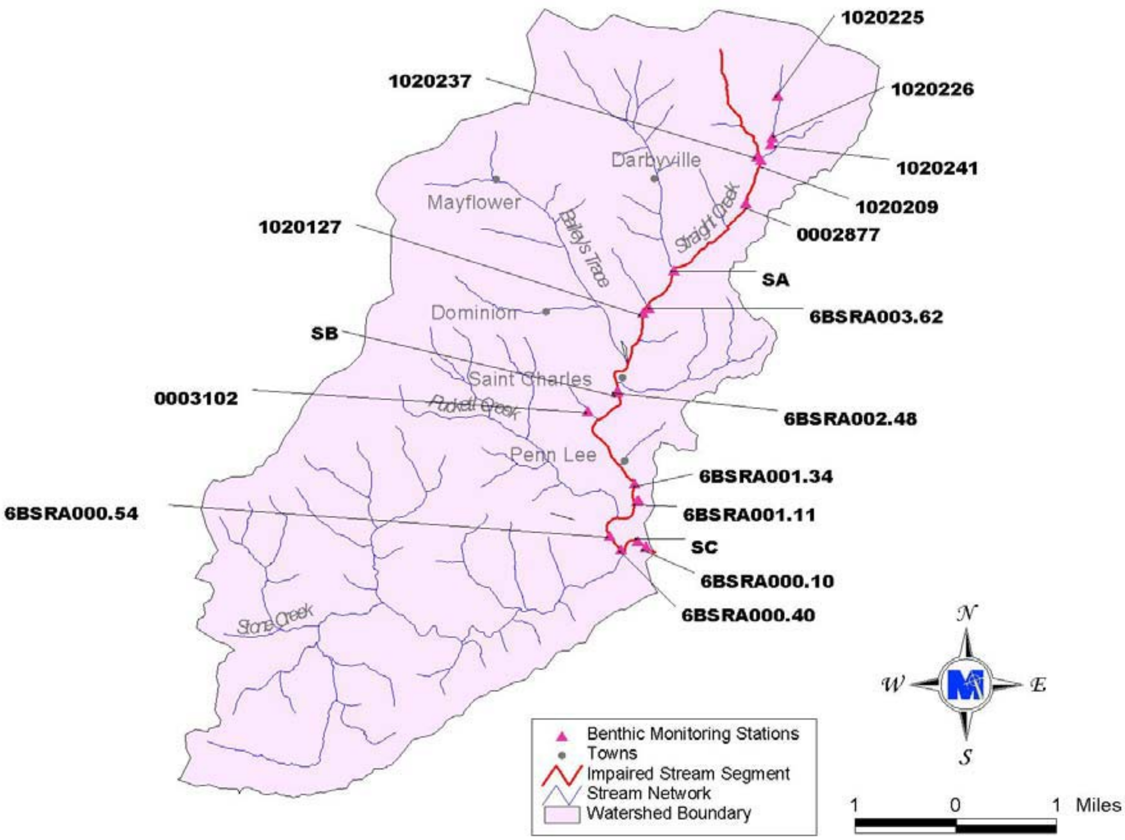

Figure 6.1 Biological and ambient water quality monitoring stations on Straight Creek.

Table 6.3 RBP II biological monitoring data for VADEQ station 6BSRA000.40 on Straight Creek.

Station:	6CWLC009.63	6BSRA000.40	6CWLC009.63	6BSRA000.40	6CWLC009.63	6BSRA000.40	6ADIS002.80	6BSRA000.40	6ADIS002.80	6BSRA000.40
Metric	**3/91**	**5/91**	**11/91**	**11/91**	**4/92**	**5/92**	**12/92**	**12/92**	**12/93**	**11/93**
Taxa Rich	15	7	23	10	17	9	10	10	12	9
MFBI	4	6	3	5	4	7	4	6	4	6
SC/CF	9	0	1	0.30	4	0	0.54	0.05	0.70	0.01
EPT/Chi Abund	25	0.83	24	0.84	10	0.03	50	3	16	12
% Dom	48	42	24	47	40	58	30	59	21	66
EPT Index	9	2	13	4	9	2	7	4	7	3
Comm. Loss Index	0	2	0	2	0	1	0	0.60	0	0.56
SH/Tot	0.01	0	0.15	0.10	0.02	0.01	0.09	0.02	0.14	0.00
Bio Cond Score	42	6	46	14	44	12	46	14	46	18
RBP II Score	100%	14%	100%	30%	100%	27%	100%	30%	100%	39%
Assessment*	Ref	SV	Ref	MI	Ref	MI	Ref	MI	Ref	MI

*Ref = Reference, SV = Severely Impaired, MI = Moderately Impaired, SI = Slightly Impaired

Table 6.4 RBP II biological monitoring data for 4 VADEQ stations on Straight Creek.

Station:	6BPLL006.50	6BSRA000.40	6AMCR000.55	6BSRA000.11	6BPLL006.50	6BSRA002.48	6BPLL006.50	6BSRA003.62	6BNFH085.31	6BSRA000.11	6CMFH045.83	6BSRA003.62
Metric:	**9/99**	**9/99**	**10/99**	**9/99**	**9/99**	**9/99**	**9/99**	**9/99**	**11/03**	**12/03**	**11-03**	**12-03**
Taxa Rich	13	8	14	7	13	12	13	11	14	8	11	10
MFBI	4.078	5.66	3.75	5.65	4.078	4.941	4.078	5.08	3.87	4.59	4.69	5.39
SC/CF	2.923	0	1.75	0	2.923	0.088	2.923	1.1111	1.17	0.39	0.50	0.16
EPT/Chi Abund	2.9	1.84	92	1.24	2.9	2.643	2.9	0.88	36.50	4.00	12.29	2.89
% Dom	33.01	50	29	36.6	33.01	37.25	33.01	30	30.43	33.33	43.52	53.33
EPT Index	7	3	7	2	7	5	7	3	8	5	8	5
Comm. Loss Index	0	1	0	1	0	1	0	0.73	0	1	0	0.3
SH/Tot	0.01	0	0.01	0.01	0.01	0.03	0.01	0.02	0.01	0.18	0.03	0.09
Bio Cond Score	44	16	46	16	44	30	44	28	44	20	42	26
RBP II Score (%)	100%	36%	100%	35%	100%	68%	100%	63%	100%	45%	100%	62%
Assessment*	Ref	MI	Ref	MI	Ref	SI	Ref	SI	Ref	MI	Ref	SI

*Ref = Reference, SV = Severely Impaired, MI = Moderately Impaired, SI = Slightly Impaired

Table 6.5 RBP II biological monitoring data for VADEQ stations on Straight Creek, Spring 2004.

Station:	**6CSFH098.10**	**6BSRA000.11**	**6CPSM017.73**	**6BSRA003.62**
Metric:	**5/11/2004**	**6/7/2004**	**4/29/2004**	**6/7/2004**
Taxa Rich	12	8	15	8
MFBI	4.2	5.01	3.98	4.76
SC/CF	1.7	0.05	2.25	0.05
EPT/Chi Abund	3.07	0.83	6.64	3.67
% Dom	28.04	46.67	37.74	52
EPT Index	6	3	9	6
Comm. Loss Index	0.00	0.88	0.00	1.25
SH/Tot	0.04	0.13	0.09	0.03
Bio Cond Score	46	20	44	16
RBP II Score	100	43.48	100	36.36
Assessment*	Ref	MI	Ref	MI

*Ref = Reference, SV = Severely Impaired, MI = Moderately Impaired, SI = Slightly Impaired

An alternative method, the Virginia Stream Condition Index (VASCI), has been developed and shows promise. Data is being collected to calibrate and further validate the VASCI method. The advantage of the VASCI is that the score does not depend on values from a reference station. The VASCI has an impairment threshold of 61.3. The VASCI scores for the VADEQ surveys are presented in Tables 6.6, 6.7 and 6.8. The VASCI scores for all nine VADEQ surveys on Straight Creek were below the impairment threshold of 61.3 (Figure 6.2).

Table 6.6 VASCI data for VADEQ station 6BSRA000.40 on Straight Creek and reference stations.

Station:	6CWLC009.63	6BSRA000.40	6CWLC009.63	6BSRA000.40	6CWLC009.63	6BSRA000.40	6ADIS002.80	6BSRA000.40	6ADIS002.80	6BSRA000.40
Metric	**3/91**	**5/91**	**11/91**	**11/91**	**4/92**	**5/92**	**12/92**	**12/92**	**12/93**	**11/93**
Richness Score	68.18	31.82	100	45.45	77.27	40.91	45.45	45.45	54.55	40.91
EPT Score	81.82	18.18	100	36.36	81.82	18.18	63.64	36.36	63.64	27.27
% Ephem. Score	100	40.07	94.69	25.68	100	1.60	72.50	8.68	33.29	15.43
%PT-H* Score	41.61	0.00	39.29	7.80	21.87	2.75	52.02	0.00	65.93	0.00
%Scraper Score	80.65	0.00	47.37	17.92	48.29	1.58	53.76	6.86	60.90	27.24
%Chironomidae Score	96.30	57.89	96.50	52.78	92.22	42.16	98.15	75.53	95.92	93.92
%2Dominant Score	44.09	48.10	83.75	45.43	57.03	16.98	62.80	24.56	85.40	28.28
%MFBI Score	91.91	61.92	96.57	70.81	91.49	49.02	89.46	63.83	88.99	65.08
VASCI Score	75.57	32.25	82.27	37.78	71.25	21.65	67.22	32.66	68.58	37.27

*%PT – Hydropsychidae

Table 6.7 VASCI data for 4 VADEQ stations on Straight Creek and reference stations.

Station:	6BPLL006.50	6BSRA000.40	6BPLL006.50	6BSRA000.11	6BPLL006.50	6BSRA002.48	6BPLL006.50	6BSRA00 3.62	6CNFH085.31	6BSRA000.11	6CMFH045.83	6BSRA003.62
Metric	**9/99**	**9/99**	**9/99**	**9/99**	**9/99**	**9/99**	**9/99**	**9/99**	**11/03**	**12/03**	**11//03**	**12/03**
Richness Score	59.09	36.36	59.09	31.82	59.09	54.55	59.09	50.00	63.64	36.36	50	45.45
EPT Score	63.64	27.27	63.64	18.18	63.64	45.45	63.64	27.27	72.73	45.45	72.73	45.45
% Ephem. Score	34.84	7.55	34.84	20.39	34.84	11.20	34.84	13.05	62.42	28.07	49.85	10.88
%PT-H* Score	5.45	0.00	5.45	0.00	5.45	0.00	5.45	0.00	14.66	51.35	15.61	3.12
%Scraper Score	100	22.40	100	15.84	100	64.83	100	62.90	77.14	24.28	40.32	14.34
%Chironomidae Score	90.29	70.37	90.29	63.39	90.29	86.27	90.29	75.00	98.26	82.80	93.52	78.89
%2Dominant Score	71.45	29.39	71.45	43.81	71.45	48.10	71.45	64.94	70.27	69.82	62.80	36.88
%MFBI Score	87.09	63.86	87.09	63.94	87.09	74.39	87.09	72.35	90.15	79.54	78.16	67.81
VASCI Score	63.98	32.15	63.98	32.17	63.98	48.10	63.98	45.69	68.66	52.21	57.87	37.85

*%PT – Hydropsychidae

Table 6.8 VASCI data for 4 VADEQ stations on Straight Creek and reference stations.

Station:	6CSFH098.10	6BSRA000.11	6CPSM017.73	6BSRA003.62
Metric	**5/11/2004**	**6/7/2004**	**4/29/2004**	**6/7/2004**
Richness Score	72.73	36.36	59.09	36.36
EPT Score	90.91	54.55	63.64	27.27
% Ephem. Score	88.43	88.09	43.40	16.31
%PT-H* Score	28.88	8.43	33.50	21.85
%Scraper Score	45.22	4.84	69.55	12.54
%Chironomidae Score	89.72	79.00	86.24	53.33
%2Dominant Score	74.17	38.96	79.43	46.5
%MFBI Score	88.79	77.06	85.81	73.37
VASCI Score	72.35	48.40	65.08	35.94

*%PT – Hydropsychidae

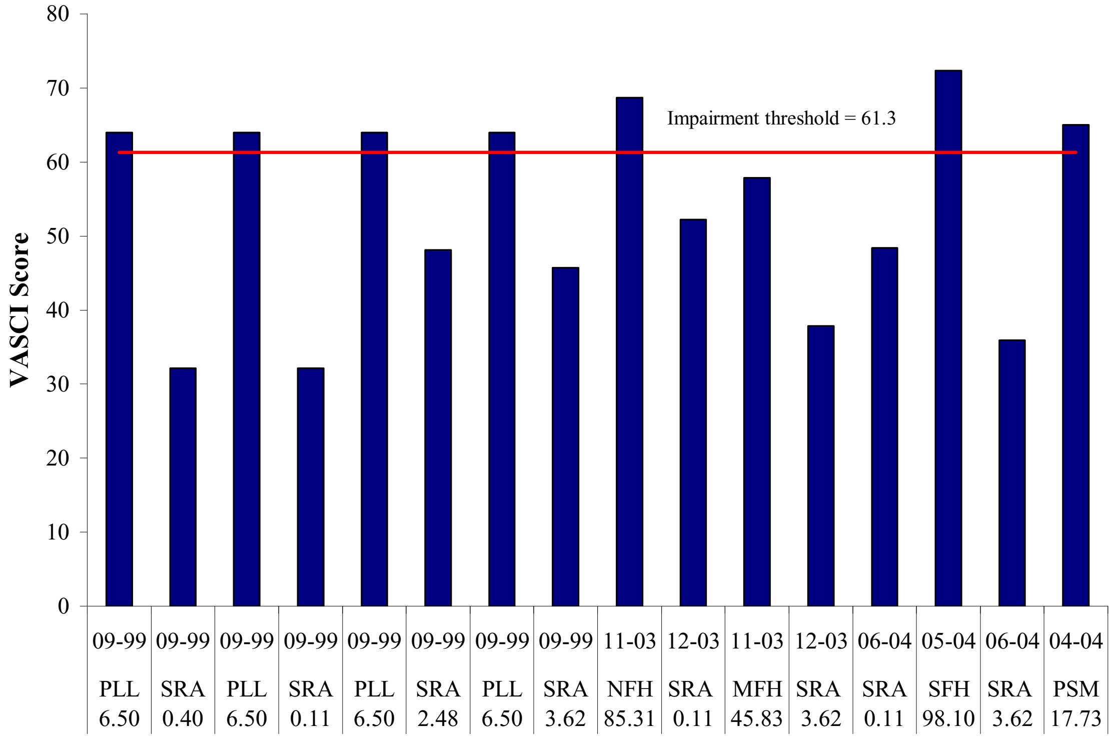

Figure 6.2 VASCI scores for VADEQ benthic surveys on Straight Creek.

On July 18, 2002 and November 7, 2002, Environmental Concepts, Inc. (ECI) performed additional benthic surveys at three sites on Straight Creek under contract from Virginia Division of Mines, Minerals, and Energy (DMME). Detailed results of the surveys are shown in Table 6.9 and 6.10 and Figure 6.3. The VASCI scores for all six surveys are below the impairment threshold of 61.3. Scores improved slightly from upstream to downstream.

Table 6.9 ECI benthic monitoring stations on Straight Creek.

Station	River Mile	Location
SC	0.19	Below Stone Creek
SB	2.40	Below Big Branch
SA	3.84	Just above Gin Creek

Table 6.10 VASCI data for the ECI benthic surveys on Straight Creek.

Metric	Station					
	SA 7/02	SA 11/02	SB 7/02	SB 11/02	SC 7/02	SC 11/02
Tot Taxa	12	16	15	16	13	19
EPT Tax	3	3	5	5	4	4
%Ephem	4	7	6	24	36	12
%PT-Hydropsychidae*	1		1	0	2	
%Scrap	2	5	3	6	9	26
%Chiro	3	2	7	0	11	7
%2Dom	77	57	73	80	52	61
HBI	5	5	5	5	4	5
VASCI	37.31	43.08	41.63	46.89	51.96	50.18

*%PT – Hydropsychidae

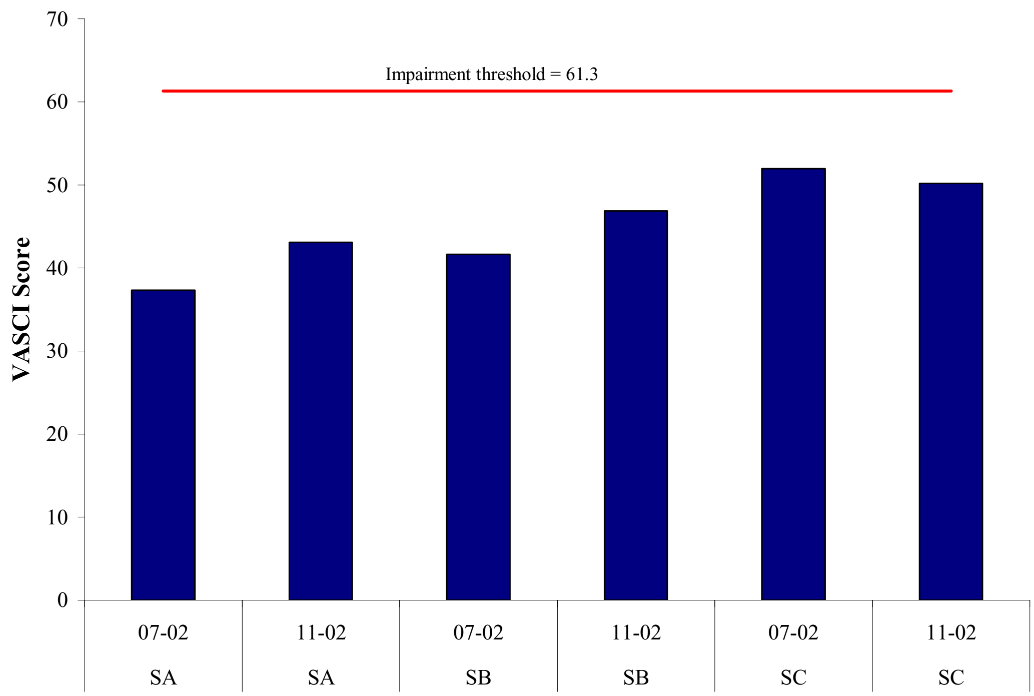

Figure 6.3 VASCI scores for ECI monitoring sites on Straight Creek.

In 1998 the United States Army Corps of Engineers (USACE) began multiyear Powell River Ecosystem Restoration Project which includes water quality monitoring and water quality studies. The Virginia Tech Biology Department was contracted to conduct an integrative bioassessment study in the watershed that resulted in the collection of benthic organisms in the Straight Creek watershed (Table 6.11). The study provided an ecotoxicological restoration potential (ETR) for five watersheds in the Powell River Basin. Based on the ETR score for the Straight Creek watershed this study concluded that it was more influenced by urban land uses than past and present mining activities. It should be noted the worst of these influences, uncontrolled discharges from single family homes, are being addressed by the fecal coliform TMDL. The maximum conductivity value reported was 774 μmhos/cm at station SC2. Data collected by the regulatory agencies and additional data collected by the USACE contractors at these sites in Straight Creek show numerous conductivity values above 1,000 μmhos/cm with a maximum value of 5,800 μmhos/cm. Conductivities above 1,000 μmhos/cm are inconsistent with the type urban land use found in Straight Creek, but are consistent with mining land uses. This indicates that mining impacts on water quality in the Straight Creek watershed are much more pronounced than the Virginia Tech study found (Cherry, D.S 2001). All three results were well below the VASCI impairment threshold of 61.3.

Table 6.11 VASCI data for benthic surveys on Straight Creek performed by the Virginia Tech Biology Department in 2000.

Metric	Station		
	SC2 River Mile 4.16	SC6C River Mile 3.63	SW 19 River Mile 0.54
Tot Taxa	54.55	54.55	72.73
EPT Tax	18.18	27.27	45.45
%Ephem	0.73	12.25	14.42
%PT-Hydropsychidae*	0.00	0.00	2.61
%Scrap	4.32	14.39	15.00
%Chiro	57.59	77.46	71.63
%2Dom	31.57	42.68	44.97
HBI	66.64	68.83	67.72
VASCI	29.2	37.18	41.82

*%PT – Hydropsychidae

6.3 Habitat Assessments

Benthic impairments have two general causes: input of pollutants to streams and alteration of habitat in either the stream or the watershed. Habitat can be altered directly (*e.g.,* by channel modification), indirectly (because of changes in the riparian corridor leading to conditions such as streambank destabilization), or even more indirectly (*e.g.,* due to land use changes in the watershed such as clearing large areas).

Habitat assessments are normally carried out as part of the benthic sampling. The overall habitat score is the sum of ten individual metrics, each metric ranging from 0 to 20. The classification schemes for both the individual habitat metrics and the overall habitat score for a sampling site are shown in Table 6.12.

Table 6.12 Classification of habitat metrics based on score.

Habitat Metric	Optimal	Sub-optimal	Marginal	Poor
Embeddedness	16 - 20	11 – 15	6 - 10	0 - 5
Epifaunal Substrate	16 - 20	11 – 15	6 - 10	0 - 5
Pool Sediment	16 - 20	11 – 15	6 - 10	0 - 5
Flow	16 - 20	11 – 15	6 - 10	0 - 5
Channel Alteration	16 - 20	11 – 15	6 - 10	0 - 5
Riffles	16 - 20	11 – 15	6 - 10	0 - 5
Velocity	16 - 20	11 – 15	6 - 10	0 - 5
Bank Stability	18 - 20	12 – 16	6 - 10	0 - 4
Bank Vegetation	18 - 20	12 – 16	6 - 10	0 - 4
Riparian Vegetation	18 - 20	12 – 16	6 - 10	0 - 4

6.3.1 Habitat Assessment at Biological Monitoring Stations

Habitat assessment for Straight Creek will include an analysis of habitat scores recorded by the VADEQ biologist and the ES&C benthic surveys. The VADEQ habitat assessments at Straight Creek monitoring station 6BSRA000.40 are displayed in Table 6.13. The habitat metrics related to sediment, embeddedness and sediment deposition had median scores of 7 and 8, respectively. This is indicative of large-scale movements of sediment in the stream and an unstable environment for the macroinvertebrate population. A marginal score for embeddedness indicates that 50 to 75% of the hard substrate in a riffle is surrounded by fine sediment which greatly affects the amount of habitat available to aquatic organisms. Marginal sediment deposition scores indicate that 30 to 50% of the pool bottom is covered with fine sediment. In addition, bank stability scores were marginal indicating that 30 to 60% of the streambank has areas of erosion which contribute to the sediment problems previously discussed. Riparian vegetation scored in the marginal category. A healthy riparian zone acts as a buffer for pollutants running off the land, helps prevent erosion, and provides habitat. Bank vegetation also scored in the marginal category. The lack of proper streambank vegetation is another indication of erosion potential. Another metric that had marginal scores was velocity. Streams with the best habitat have four distinct velocity/depth patterns that provide a diverse habitat for macroinvertebrates. A marginal score indicates that only two different patterns were present. Channel flow is a metric that describes how much of the available substrate is covered by water. Straight Creek had marginal scores for this metric which means that only 25 to 75% of the available substrate was covered by water. The frequency of riffles is also an important measure of available habitat. Straight Creek had marginal scores for this metric, which indicates the stream is characterized by occasional riffles or bend areas.

Table 6.13 Habitat scores at VADEQ benthic monitoring station 6BSRA000.40 on Straight Creek.

Metric	05-91	11-91	05-92	12-92	11-93	09-99	Median
ALTERATION	11	12	6	13	13	16	12.5
BANK STABILITY	5	8	8	8	4	7	7.5
BANK VEGETATION	5	10.5	9	8	5.5	14	8.5
EMBEDDEDNESS	7	7	7	9	6	6	7
FLOW	12	11.5	7.5	8.5	4	7	8
RIFFLES	10	8	6	9	7	7	7.5
RIPARIAN VEGETATION	7	10.5	9	9	2	6	8
SEDIMENT DEPOSITION	9	8	8	8	8	6	8
EPIFAUNAL SUBSTRATE	17	17	17	17	16	17	17
VELOCITY	8	7	7	7	11	6	7

A special benthic survey was performed on Straight Creek by VADEQ in September of 1999 and three additional sites were monitored. The results of those surveys are presented in Table 6.14.

Table 6.14 Habitat scores at three additional VADEQ benthic monitoring stations on Straight Creek (9/22/1999).

Metric	6BSRA000.11	6B SRA002.48	6B SRA003.62
ALTERATION	14	18	14
BANK STABILITY	8	5	3
BANK VEGETATION	15	5	9
EMBEDDEDNESS	13	9	10
FLOW	7	7	7
RIFFLES	7	7	10
RIPARIAN VEGETATION	5	5	5
SEDIMENT DEPOSITION	5	10	10
EPIFAUNAL SUBSTRATE	16	9	6
VELOCITY	6	8	7

The habitat scores for these stations are very consistent with those for station 6BSRA000.40. The most striking difference was for the epifaunal substrate metric at stations 6BSRA002.48 and 6BSRA003.62. This metric is a measure of how stable the available substrate is. Marginal scores indicate that it is subject to frequent disturbance and/or removal. The most recent benthic monitoring performed in Straight Creek by the VADEQ was in the fall of 2003 and spring of 2004. Those results are shown in Table 6.15.

Table 6.15 Fall 2003 and Spring 2004 habitat scores at VADEQ benthic monitoring stations on Straight Creek.

Metric	6BSRA000.11	6B SRA003.62	6BSRA000.11	6B SRA003.62
	12/09/2003	12/09/2003	06/07/2004	06/07/2004
ALTERATION	15	15	18	18
BANK STABILITY	6	9	6	11
BANK VEGETATION	6	13	10	13
EMBEDDEDNESS	17	15	14	13
FLOW	15	18	15	18
RIFFLES	16	11	16	17
RIPARIAN VEGETATION	6	9	8	12
SEDIMENT DEPOSITION	11	13	9	10
EPIFAUNAL SUBSTRATE	18	18	15	17
VELOCITY	16	17	10	13

The more recent monitoring shows improvements in many of the habitat parameters at these two monitoring stations. Embeddedness and sediment deposition showed considerable improvement at station 6ASRA000.11. Scores for bank stability, bank vegetation and riparian vegetation remained in the marginal category. Embeddedness scores were much better at station 6ASRA003.62 but sediment deposition, bank stability and riparian vegetation scores remain in the marginal category.

The ECI habitat scores are presented in Table 6.16. Station SC, located near the VADEQ monitoring station 6BSRA000.11, had marginal scores for most of the same metrics that the VADEQ station had in 1999. Unfortunately, embeddedness was not reported. Station SB, located near the VADEQ station 6BSRA002.48, had marginal scores for riparian vegetation and bank stability. Sediment deposition scores were suboptimal.

Station SA, located just above the confluence with Gin Creek, is close to the VADEQ station 6BSRA003.62. This station reported no marginal habitat scores. This could indicate some improvement in conditions in this portion of the stream since 1999, but the two sites are at different locations and it is possible that the ECI site had better habitat.

Table 6.16 Habitat scores for the three ECI benthic stations on Straight Creek.

Metric	SA 7/18/02	SA 11/7/02	SB 7/18/02	SB 11/7/02	SC 7/18/02	SC 11/7/02
ALTERATION	17	17	16	16	13	13
BANK STABILITY	16	16	6	6	10	10
BANK VEGETATION	14	14	12	12	13	13
FLOW	11	11	12	12	9	9
RIPARAIN VEGETATION	15	15	8	8	10	10
SEDIMENT DEPOSITION	17	17	13	13	9	9
EPIFAUNAL SUBSTRATE	15	15	17	17	13	13

6.4 Discussion of In-stream Water Quality

This section provides an inventory of available observed in-stream monitoring data throughout the Straight Creek watershed. An examination of data from water quality stations used in the Section 305(b) assessment and data collected during TMDL development were analyzed. Sources of data and pertinent results are discussed.

6.4.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information for Straight Creek are:

- Data collected at nine VADEQ stations,
- Data collected at nine sites monitored by private coal mining companies for mining permit application or compliance and supplied by DMME, and
- Data collected at nine sites by Engineering Concepts, Inc (ECI) and supplied by DMME.

Each station included in the DMME permit-monitoring database has been assigned unique monitoring point identification (MPID) number.

6.4.1.1 VADEQ Water Quality Monitoring

VADEQ has monitored water quality recently at nine sites on Straight Creek (Table 6.17). The locations of these stations are shown in Figure 6.1. Only stations with at least nine data points were used in the stressor identification evaluation unless extreme values were reported. This was done for statistical accuracy and to ensure that data was collected in every season. The data for the stations is summarized in Tables 6.18 through 6.27. Conductivity values are high throughout all stations.

Table 6.17 VADEQ monitoring stations on the Straight Creek watershed from January 1990 through March 2004.

Station	Type	Data Record	# Samples
6BSRA000.10	Ambient	8/03 - 3/04	4
6BSRA000.11	Special Study	10/00	1
6BSRA000.40	Special Study	8/03	1
6BSRA000.54	Special Study	10/00	1
6BSRA001.10	Special Study	10/00	1
6BSRA001.11	Ambient	1/90 - 3/04	66
6BSRA003.22	Ambient/ Special Study	7/03 - 3/04	9
6BSRA003.62	Special Study	8/03	1
6BSRA004.16	Ambient	7/03 - 3/04	9

Table 6.18 In-stream water quality data at 6BSRA000.10 on Straight Creek (8/03-2/04).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
DO	12	12.505	14.5	7.98	3	4	--
PH	8.08	8.0	8.5	7.8	0.33	4	--
TEMP (C)	10.40	9.2	19.2	4.0	6.91	4	--
TP (mg/L AS P)	0.010	0.01	0.010	0.01	0.00	4	--
Nitrite + Nitrate (mg/L AS N)	0.35	0.36	0.39	0.3	0.04	4	--
TN (mg/L AS N)	0.6	0.501	0.8	0.4	0.2	4	--

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.19 In-stream water quality data at 6BSRA000.11 on Straight Creek (10/31/00).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
Al DISSOLVED (µg/L)	4.8	4.8	4.8	4.8	--	1	--
Sb DISSOLVED (µg/L)	0.11	0.11	0.11	0.11	--	1	--
As DISSOLVED (µg/L)	0.21	0.21	0.21	0.21	--	1	--
Ca DISSOLVED (mg/L)	47.60	47.60	47.60	47.60	--	1	--
Cl, TOTAL (mg/L)	13.6	13.6	13.6	13.6	--	1	--
Conductivity (µmho/cm)	770	770	770	770	--	1	--
Cu, DISSOLVED (µg/L)	0.49	0.49	0.49	0.49	--	1	--
PH	8.57	8.57	8.57	8.57	--	1	--
Mg DISSOLVED (mg/L)	18.8	18.8	18.8	18.8	--	1	--
Mn DISSOLVED (mg/L)	6.28	6.28	6.28	6.28	--	1	--
Ni DISSOLVED (mg/L)	0.55	0.55	0.55	0.55	--	1	--
Nitrite + Nitrate (mg/L AS N)	0.52	0.5	0.76	0.4	0.04	4	--
TEMP (C)	9.86	9.86	9.86	9.86	--	1	--
TP (mg/L AS P)	0.01	0.01	0.01	0.01	0.01	4	--

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.20 In-stream water quality data at 6BSRA000.40 on Straight Creek (8/6/03).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
Conductivity (µmho/cm)	936	936	936	936	--	1	--
DO	8.02	8.02	8.02	8.02	--	1	--
PH	8.21	8.21	8.21	8.21	--	1	--
TEMP (C)	19.1	19.1	19.1	19.1	--	1	--

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.21 In-stream water quality data at 6BSRA000.54 on Straight Creek (10/31/00).

Water Quality Constituent	Mean	Median	Max	Min	SD1	N2	Trend3
Al DISSOLVED (µg/L)	3.5	3.5	3.5	3.5	--	1	--
Sb DISSOLVED (µg/L)	0.12	0.12	0.12	0.12	--	1	--
As DISSOLVED (µg/L)	0.20	0.20	0.20	0.20	--	1	--
Cd DISSOLVED (mg/L)	0.24	0.24	0.24	0.24	--	1	--
Ca DISSOLVED (mg/L)	38.5	38.5	38.5	38.5	--	1	--
Cl TOTAL (mg/L)	15.2	15.2	15.2	15.2	--	1	--
Conductivity (µmho/cm)	847	847	847	847	--	1	--
Cu DISSOLVED (µg/L)	0.53	0.53	0.53	0.53	--	1	--
PH	8.60	8.60	8.60	8.60	--	1	--
Mg DISSOLVED (mg/L)	14.5	14.5	14.5	14.5	--	1	--
Mn DISSOLVED (mg/L)	2.35	2.35	2.35	2.35	--	1	--
Ni DISSOLVED (mg/L)	0.61	0.61	0.61	0.61	--	1	--
TEMP (C)	9.32	9.32	9.32	9.32	--	1	--

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.22 In-stream water quality data at 6BSRA001.10 on Straight Creek (10/31/00).

Water Quality Constituent	Mean	Median	Max	Min	SD1	N2	Trend3
Al, DISSOLVED (µg/L)	16.2	16.2	16.2	16.2	--	1	--
Sb DISSOLVED (µg/L)	0.14	0.14	0.14	0.14	--	1	--
As DISSOLVED (µg/L)	0.23	0.23	0.23	0.23	--	1	--
Cd DISSOLVED (mg/L)	0.24	0.24	0.24	0.24	--	1	--
Ca DISSOLVED (mg/L)	37.8	37.8	37.8	37.8	--	1	--
Cl, TOTAL (mg/L)	11.1	11.1	11.1	11.1	--	1	--
Conductivity (µmho/cm)	834	834	834	834	--	1	--
Cu, DISSOLVED (µg/L)	0.55	0.55	0.55	0.55	--	1	--
PH	8.69	8.69	8.69	8.69	--	1	--
Mg DISSOLVED (mg/L)	14.0	14.0	14.0	14.0	--	1	--
Mn DISSOLVED (mg/L)	4.41	4.41	4.41	4.41	--	1	--
Ni DISSOLVED (mg/L)	1.15	1.15	1.15	1.15	--	1	--
TEMP (C)	8.58	8.58	8.58	8.58	--	1	--

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.23 In-stream water quality data at 6BSRA001.11 on Straight Creek (7/90—3/04), Part 1.

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
Al DISSOLVED (µg/L)	148.00	148.00	148.00	148.00	--	1	--
Al SEDIMENT (mg/kg DRY WGT)	10,818	10,300	15,600	4,480	3913	7	--
AMMONIA, TOTAL (mg/L AS N)	0.09	0.06	0.22	0.04	0.05	19	—
Sb DISSOLVED (µg/L)	0.17	0.17	0.17	0.17	--	1	--
Sb SEDIMENT (mg/kg DRY WGT)	9.0	9.0	11	7	2.83	2	--
As DISSOLVED (µg/L)	0.33	0.33	0.33	0.33	--	1	--
As SEDIMENT (mg/kg DRY WGT)	7.43	6.7	12	5.0	2.62	7	--
Be SEDIMENT (mg/kg DRY WGT)	1.0	1.0	1.0	1.0	--	1	--
BOD (mg/L)	1.55	1.0	6.0	1.0	1.1	28	—
Ca DISSOLVED (mg/L)	41.0	41.0	41.0	41.0	--	1	--
Cl, TOTAL (mg/L)	8.08	7.3	20.8	1.3	4.84	53	—
Cr DISSOLVED (mg/L)	0.25	0.25	0.25	0.25	--	1	--
Cr SEDIMENT (mg/kg DRY WGT)	15.02	14.85	20.0	9.0	3.55	10	--
COD (mg/L)	27.5	7.0	410	1.0	72.5	34	—
Conductivity (µmho/cm)	1079	651	10269	40.1	1747	66	—
Cu, DISSOLVED (µg/L)	1.18	1.18	1.18	1.18	--	1	--
Cu SEDIMENT (mg/kg DRY WGT)	29.0	26.7	46.7	16.0	10.3986	10	--
Cu, TOTAL (µg/L)	10.0	10.0	10.0	10.0	--	1	--
DO	10.66	10.65	15.06	7.23	1.87	64	—
PH	8.06	8.10	8.57	7.42	0.28	66	—
FIXED SOLIDS (mg/L)	495	398	1800	189	290	55	—
FIXED SUSPENDED SOLIDS (mg/L)	84	6.0	1280	1.0	252	33	—
F, TOTAL (mg/L)	0.19	0.16	0.65	0.12	0.13	16	—
HARDNESS (mg/L AS $CaCO_3$)	191	161	1500	90	202	56	—
Fe, SEDIMENT (mg/kgG AS DRY WT)	30547	26500	48900	19800	11445	7	--
Pb, SEDIMENT (mg/kg DRY WT)	24.929	26.35	43	10	10.8068	10	--
Mg DISSOLVED (mg/L)	16	16	16	16	--	1	--
Mg TOTAL (mg/L)	16264	15660	21510	10480	4182	5	--
Mn DISSOLVED (mg/L)	93	93	93	93	--	1	--
Mn SEDIMENT (mg/kg DRY WGT)	898	756	1630	452	413.515	7	--
Ni DISSOLVED (mg/L)	5.66	5.66	5.66	5.66	--	1	--
Ni SEDIMENT (mg/kg DRY WGT)	41.0	43.0	64.5	19.0	16.7	10	--
Ni TOTAL (mg/L)	31.75	31.75	31.75	31.75	--	1	--

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.24 In-stream water quality data at 6BSRA001.11 on Straight Creek (7/90—3/04), Part 2.

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
NITRATE, TOTAL (mg/L AS N)	0.57	0.55	1.38	0.18	0.24	55	—
Nitrite + Nitrate (mg/L AS N)	0.52	0.5	0.76	0.4	0.10	9	--
Nitrite, TOTAL (mg/L AS N)	0.022	0.010	0.130	0.010	0.027	22	—
TKN (mg/L AS N)	0.34	0.2	3.6	0.1	0.55	52	—
N, TOTAL (mg/L)	0.644	0.636	0.86	0.53	0.10312	9	--
ORTHOPHOSPHORUS (mg/L AS P)	0.09	0.015	0.40	0.01	0.15	10	--
TP (mg/L AS P)	0.052	0.020	0.60	0.01	0.11	49	—
Se, DISSOLVED (µg/L)	1.5	1.5	1.5	1.5	--	1	--
Se, SEDIMENT (mg/kgDRY WT)	4.5	1.7	16	1	6.4	5	--
Se, TOTAL (µg/L)	10	10	10	10	--	1	--
TANNIN AND LIGNIN (mg/L)	1.62	1.62	1.62	1.62	--	1	--
TEMP (C)	13.6	13.2	26.5	2.6	6.4	67	--
THALLIUM, SEDIMENT (mg/kg DRY WT)	5.0	5.0	5.0	5.0	--	1	--
TOTAL ORGANIC CARBON (mg/L)	2.31	1.65	6.54	1	1.44	31	—
TOTAL SOLIDS (mg/L)	544	447	1860	212	305	55	—
VOLATILE SOLIDS (mg/L)	48.5	44	200	16	26.6	55	—
VOLATILE SUSPENDED SOLIDS (mg/L)	15.6	3	180	1	37.6	29	—
Zn, DISSOLVED (ug/L)	1.95	1.95	1.95	1.95	--	1	--
Zn, SEDIMENT (mg/kgDRY WT)	161.0	179	231	72	56.9	10	--
Zn, TOTAL (µg/L)	21.1	11.7	51.0	10	--	1	--

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.25 In-stream water quality data at 6BSRA003.22 on Straight Creek (7/03—3/04).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
Al, DISSOLVED (µg/L)	0.15	0.10	0.40	0.040	0.14	5	--
Conductivity (µmho/cm)	1345	1234	2251	582	551	9	--
DO	11.2	11.4	14.7	8.18	2.3	9	--
PH	8.42	8.43	8.74	8.21	0.17	9	--
Nitrite + Nitrate (mg/L AS N)	0.56	0.57	0.85	0.27	0.15	9	--
N, TOTAL (mg/L)	0.78	0.75	0.97	0.62	0.12	9	--
TEMP (C)	11.2	11.8	20.6	2.1	6.5	10	--
TP (mg/L AS P)	0.014	0.010	0.02	0.01	0.005	8	--

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.26 In-stream water quality data at 6BSRA003.62 on Straight Creek (8/6/03).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
Conductivity (µmho/cm)	521	521	521	521	--	1	--
DO	8.06	8.06	8.06	8.06	--	1	--
PH	8.20	8.20	8.20	8.20	--	1	--
TEMP (C)	18.30	18.30	18.30	18.30	--	1	--

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.27 In-stream water quality data at 6BSRA004.16 on Straight Creek (7/03—3/04).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
Conductivity (µmho/cm)	425	320	1059	253.0	248	9	--
DO	11.16	12.31	13.86	7.87	2.36	9	--
PH	8.18	8.09	9.28	7.555	0.48	9	--
Nitrite + Nitrate (mg/L AS N)	0.74	0.68	1.9	0.14	0.49	9	--
TEMP (C)	11.1	11.9	20.9	1.4	6.9	10	--
TP (mg/L AS P)	0.017	0.020	0.03	0.01	0.01	9	--
N, TOTAL (mg/L)	0.90	0.81	2.06	0.30	0.48	9	--

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

There have been a number of pollution response (PReP) incidents in the Straight Creek watershed over the past nine years. The major incidents that VADEQ has responded to are summarized below by pollution compliant number.

PC 95-0478 – 3/14/95

> Polymer was added to a roadside settling basin owned by Lone Mountain Processing, Inc. (LMPI) to improve settling. The basin was not totally sealed and an unknown quantity reached state waters including Straight Creek. The result was 4,320 dead fish, including minnows and suckers. The spill impacted fish all the way to the mouth of Straight Creek.

PC 97-0135 – 10/24/1996

> Subsidence in a LMPI impoundment caused coal slurry to reach a network of underground mines. Coal slurry consists of coal fines, water, and a variety of chemicals used to wash coal. The majority of the contaminants are considered PAHs (Polynuclear aromatic hydrocarbons). The slurry entered state surface

waters at Gin Creek and killed 11,240 fish in 8.5 miles involving Straight Creek and the North Fork Powell River. A consent decree between LMPI and the US Department of the Interior was entered into. The consent decree requires that LMPI pay the Department's Natural Resource Damage Assessment and Restoration Program (NRDAR) $2.45 million. This money is supposed to be earmarked for past natural resource damage, assessment costs, restoration, replacement of endangered species or acquisition of habitats which support them, and planning, implementation, oversight and monitoring. No implementation or reclamation work has been done.

PC 98-0001 – 7/1/1997

There was a blowout when water from the abandoned mine broke out of a hillside and flowed into Straight Creek. This occurred 0.4 miles north of St. Charles, VA. This mine was abandoned circa 1925. The wastewater was a low pH (3.5) and contained an extremely high concentration of iron, which precipitated in Straight Creek. The amount of water that flowed into Straight Creek is not known, but the level of water in the stream did rise because of the iron deposits on the banks. The fish kill totaled 3,133 including minnows, suckers, red-eye bass, smallmouth bass, brown trout and carp. The incident was declared an emergency in order that corrective action could be expedited. DMME dewatered the abandoned mine and put in mine seals where necessary.

A special benthic survey was carried out by VADEQ on August 7 to 9, 1997. A severe impact was found at station SRA002.69 just downstream of St. Charles. Only 49 organisms were found, less than half the minimum expected. A station further downstream, SRA000.50, compared favorably to the control station on Straight Creek, SRA003.84.

PC 2004-S-0153 – 10/9/2003

A sediment pond owned by Ghermal Coal Company breached, causing wastewater to leak into Straight Creek just upstream of St. Charles, VA. The fish kill extended to the Bailey's Trace confluence (2,479 fish were killed). The fish killed were predominantly minnows (98%).

6.4.1.2 Mine Permit Application/Compliance Monitoring

In addition to the VADEQ stations, DMME in-stream monitoring data is shown in Table 6.28 and Figure 6.1. The data from these stations were used in the stressor identification in Chapter 7.

Table 6.28 Monitoring stations on Straight Creek from data supplied by DMME.

MPID	River Mile	Data Record Begin	Data Record End
0003102*	2.12	04/99	05/99
1020127	3.26	11/95	12/04
0002877	4.87	03/98	12/04
1020209	5.32	01/95	12/04
1020237	5.37	01/95	12/04
1020241	5.57	01/95	03/98
1020226	5.64	01/95	12/04
1020180	5.97	01/95	12/04
1020225	6.06	01/95	12/04

*Only two data points, this station was not shown in the median graphs. There were no extreme values.

Tables 6.29 through 6.36 show summaries of the water quality data collected at each of the in-stream monitoring locations. Sample timing varied based on the mine permit that the sample was intended to support. Abbreviations used in these tables include: Fe (Total Iron), Mn (Total Manganese), TDS (Total Dissolved Solids), and TSS (Total Suspended Solids). All flow values that contributed to these summaries were estimated.

Conductivity and total dissolved solids are consistently high throughout the watershed, while total iron and total manganese spike at certain points in the stream and quickly return to lower levels.

Table 6.29 In-stream water quality data at MPID 0003102 (4/99—12/03).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
FLOW (gpm)	72	20.0	500	0.0	106	57	0.50
TEMP (C)	15	15.0	15	15.0	0	2	--
PH	7.8	7.8	8.3	7.2	0.8	2	--
Fe (mg/L)	1.1	1.1	1.6	0.6	0.7	2	--
Mn (mg/L)	0.1	0.1	0.1	0.1	0.0	2	--
TSS (mg/L)	14.5	14.5	20.0	9.0	7.8	2	--
ACIDITY (mg/L)	3.0	3.0	3.0	3.0	--	1	--
ALKALINITY (mg/L)	14.0	14.0	16.0	12.0	2.8	2	--
CONDUCTIVITY (µmhos/cm)	170	170	220	120	71	2	--
TDS (mg/L)	88	88	122.0	54	48.1	2	--
SULFATE (mg/L)	63	63	89.0	36.0	37.5	2	--

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.30 In-stream water quality data at MPID 1020127 (11/95—12/03).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
FLOW (gpm)	107	78	400	0	96	102	—
TEMP (C)	12.2	12.0	22.0	3.0	5.5	92	0.167
PH	7.5	7.6	8.7	6.2	0.44	97	-0.075
Fe (mg/L)	0.44	0.20	6.9	0.10	0.85	88	—
Mn (mg/L)	0.37	0.10	9.0	0.10	1.2	53	—
TSS (mg/L)	13.1	7.5	112	2.0	18.4	96	—
ACIDITY (mg/L)	0	0	0	0	0	97	—
ALKALINITY (mg/L)	80	62	296	15.0	63	97	-6.0
CONDUCTIVITY (µmhos/cm)	862	450	5,800	130	1,188	97	—
TDS (mg/L)	698	338	5,122	30.0	1,064	97	—
SULFATE (mg/L)	278	156	2,132	8.0	346	97	—

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.31 In-stream water quality data at MPID 0002877 (3/98—12/03).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
FLOW (gpm)	505	500	1,400	100	213	67	40.0
TEMP (C)	12.1	11.0	21.0	2.0	5.1	67	—
PH	7.9	8.0	8.5	6.8	0.29	67	—
Fe (mg/L)	0.34	0.10	7.0	0.10	0.96	52	-0.02
Mn (mg/L)	0.11	0.10	0.3	0.10	0.04	24	-0.02
TSS (mg/L)	10.2	4.0	284	2.0	34.6	67	—
ACIDITY (mg/L)	0	0	0	0	0	67	—
ALKALINITY (mg/L)	141	136	385	16	65	67	—
CONDUCTIVITY (µmhos/cm)	542	510	1,580	180	234	67	—
TDS (mg/L)	354	350	918	108	132	67	—
SULFATE (mg/L)	117	116	215	42.0	46.4	67	—

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.32 In-stream water quality data at MPID 1020209 (1/95—12/95).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
FLOW (gpm)	405	325	1,200	40	340	12	--
TEMP (C)	12.0	14.0	18.0	2.0	5.9	12	--
PH	7.7	7.9	8.3	7.0	0.42	12	--
Fe (mg/L)	0.43	0.25	1.2	0.10	0.33	12	--
Mn (mg/L)	0.23	0.25	0.40	0.10	0.12	6	--
TSS (mg/L)	18.8	19.5	43	4.0	13.2	12	--
ACIDITY (mg/L)	0	0	0	0	0	12	--
ALKALINITY (mg/L)	142	116	333	79	72	12	--
CONDUCTIVITY (µmhos/cm)	533	485	1,300	320	257	12	--
TDS (mg/L)	394	351	855	236	157	12	--
SULFATE (mg/L)	122	119	177	64	31.1	12	--

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.33 In-stream water quality data at MPID 1020237 (1/95—12/03).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
FLOW (gpm)	337	300	2,000	30	251	105	12.5
TEMP (C)	11.5	12.0	21.0	1.0	5.4	104	—
PH	8.0	8.0	8.5	7.0	0.32	105	—
Fe (mg/L)	0.85	0.20	33.8	0.10	3.65	90	-0.035
Mn (mg/L)	0.14	0.10	1.0	0.10	0.14	55	-0.006
TSS (mg/L)	23.8	7.0	930	2.0	96	105	-0.08
ACIDITY (mg/L)	0	0	0	0	0	105	—
ALKALINITY (mg/L)	170	140	674	14	108	105	2.41
CONDUCTIVITY (µmhos/cm)	651	535	2,620	270	355	105	12.0
TDS (mg/L)	471	387	1,596	35	259	105	—
SULFATE (mg/L)	166	138	530	35	85	105	—

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.34 In-stream water quality data at MPID 1020241 (1/95—3/98).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
FLOW (gpm)	164	75	800	10	195	39	-32.5
TEMP (C)	10.4	12.0	19.0	1.0	5.2	39	—
PH	7.8	7.9	8.2	7.0	0.30	39	0.1
Fe (mg/L)	2.0	0.40	46.0	0.10	7.5	39	—
Mn (mg/L)	0.14	0.10	0.50	0.10	0.09	37	—
TSS (mg/L)	58.6	11.0	1610	4.0	256	39	—
ACIDITY (mg/L)	0	0	0	0	0	39	—
ALKALINITY (mg/L)	123	120	213	72	42.9	39	—
CONDUCTIVITY (µmhos/cm)	407	420	630	8.0	121	39	—
TDS (mg/L)	321	308	668	156	95	39	—
SULFATE (mg/L)	95	91	202	38.0	37.8	39	—

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.35 In-stream water quality data at MPID 1020226 (1/95—12/03).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
FLOW (gpm)	103	75	800	10.0	131	105	-5.0
TEMP (C)	11.5	12.0	19.0	1.0	4.9	105	0.167
PH	7.8	7.9	8.2	7.0	0.25	105	—
Fe (mg/L)	0.6	0.20	12.9	0.10	1.69	99	-0.033
Mn (mg/L)	0.1	0.10	0.5	0.1	0.09	73	—
TSS (mg/L)	31.4	7.0	1,610	2.0	160	105	-1.0
ACIDITY (mg/L)	0	0	0	0	0	105	—
ALKALINITY (mg/L)	131	126	222	69	43.1	105	—
CONDUCTIVITY (µmhos/cm)	466	460	914	120	126	105	—
TDS (mg/L)	343	329	1,175	136	124	105	—
SULFATE (mg/L)	111	102	258	38.0	46.3	105	—

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

Table 6.36 In-stream water quality data at MPID 1020225 (1/95—12/03).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]	Trend[3]
FLOW (gpm)	78	50.0	600	5.0	101	105	-4.17
TEMP (C)	11.7	13.0	20.0	1.0	5.1	105	—
PH	7.7	7.9	8.3	0.0	0.81	105	-0.025
Fe (mg/L)	0.66	0.20	13.2	0.10	1.85	97	-0.025
Mn (mg/L)	0.11	0.10	0.40	0.10	0.05	44	—
TSS (mg/L)	24.2	8.0	590	2.0	72	105	-0.5
ACIDITY (mg/L)	0	0	0	0	0	105	—
ALKALINITY (mg/L)	108	107	354	58	41.4	105	—
CONDUCTIVITY (µmhos/cm)	421	410	700	120.0	100	105	5.0
TDS (mg/L)	293	290	505	55	79	105	-6.33
SULFATE (mg/L)	104	102	225	27.0	41.3	105	—

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--": insufficient data, "—" no trend

6.4.1.3 Water Quality Monitoring Conducted by DMME

ECI performed additional water quality monitoring during July 2002 through June 2003 under contract from DMME. Three sites were selected on Straight Creek (Figure 6.1). The results of the chemical sampling are presented in Tables 6.37 and 6.38.

Table 6.37 Results of ECI chemical monitoring in the Straight Creek watershed.

Station	Date	Flow (cfs)	Alkalinity, $CaCO_3$ (mg/L)	Conductivity (µmho/cm)	Dissolved Fe (mg/L)	Total Fe (mg/L)	Dissolved Mn (mg/L)	Total Mn (mg/L)
SA	7/18/2002	2.85	153	370	0	0.57	0	0
SA	11/7/2002	6.38	119	350	0	0.11	0	0
SA	6/5/2003	4.79	103	337	0	0.09	0	0
SB	7/18/2002	4.16	174	510	0.06	0.58	0	0
SB	11/8/2002	10	114	470	0	0.12	0	0
SB	6/5/2003	13.6	1,144	597	0	0.41	0.1	0.07
SC	7/18/2002	17.4	156	530	0.09	1.35	0	0.12
SC	11/7/2002	41.8	58	230	0	0.2	0	0
SC	6/5/2003	30.8	81	427	0	0.3	0.07	0

Table 6.38 Results of ECI chemical monitoring in the Straight Creek watershed.

Station	Date	Flow (cfs)	pH	Temp ^0C	DO (mg/L)	SO4 (mg/L)	TDS (mg/L)	TSS (mg/L)
SA	7/18/2002	2.85	6.3	16.8	7	53	326	44
SA	11/7/2002	6.38	6.7	8.7	8	112	250	11
SA	6/5/2003	4.79	8.1	18	7	79	299	10
SB	7/18/2002	4.16	6.1	18.9	7	164	503	25
SB	11/8/2002	10.01	6.4	12	8	204	290	13
SB	6/5/2003	13.56	7.9	16	7	262	488	8
SC	7/18/2002	17.35	6.3	24	7	314	532	29
SC	11/7/2002	41.76	6.4	8.9	8	88	155	10
SC	6/5/2003	30.76	8	16	9	151	347	7

6.4.1.4 Water Quality Monitoring Conducted by United States Army Corp of Engineers (USACOE)

The USACOE has an ongoing data collection process for the Powell River Ecosystem Restoration Project. Water quality data was collected from December 1998 through September 2003 at 12 monitoring stations on the mainstem of Straight Creek. Table 6.39 provides descriptive statistics for all of the data collected at the 12 sites. Data was also collected at a 13th site, SC6D (river mile 3.41), but it was inconsistent with other data collected for Straight Creek by the regulatory agencies or independent contractors. It was obvious that this data was either not collected from the mainstem or was collected in the plume of seep and did not represent typical Straight Creek stream conditions. The data for this station is not represented in Table 6.39.

Table 6.39 Results of USACOE chemical monitoring in Straight Creek.

Parameter	Mean:	Median:	Max:	Min:	SD[1]	N[2]
Temperature (C °)	13.3	12.3	25.3	0.6	6.2	217
pH (std units)	8.1	8.2	9.7	6.1	0.6	221
Dissolved Oxygen (mg/L)	10.9	10.6	17.1	7.6	2.1	83
Alkalinity, Total field (mg/L)	123	123	253	48	50	76
Aluminum, Total (mg/L)	0.93	0.22	23.90	0.05	3.44	62
Calcium (mg/L)	30.48	27.25	99.10	11.30	16.23	70
Copper (mg/L)	0.02	0.02	0.04	0.00	0.02	8
Iron, Dissolved (mg/L)	0.06	0.05	0.11	0.03	0.02	34
Iron, Total (mg/L)	0.56	0.18	11.10	0.03	1.50	70
Manganese, Total (mg/L)	0.14	0.05	1.65	0.03	0.30	39
Zinc (mg/L)	0.02	0.01	0.07	0.01	0.02	7
Specific Conductance (μmhos/cm)	781	620	4,773	144	643	219
Sulfate, (mg/L)	204	127	1,400	42	263	76
Sodium (mg/L)	117	55	939	6	174	68
Total Dissolved Solids (mg/L)	498	324	3,294	30	580	76
Total Suspended Solids (mg/L)	13	5	219	1	31	73
Flow (gpm)	4,076	1,100	46,100	9	6,992	222

[1]SD: standard deviation, [2]N: number of sample measurements

6.4.2 Trend and Seasonal Analyses

In order to improve TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on flow and water quality results. A Seasonal Kendall Test was used to examine long-term trends. The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the Seasonal Kendall Test can identify the trend (over many years) in discharge levels during a particular season or month. A seasonal analysis of water chemistry results was conducted using the Mood Median Test. This test was used to compare median values of flow and water quality in each month.

6.4.2.1 Water Chemistry Results

There are some consistent trends for stations on Straight Creek, which show decreasing trends for Fe, Mn and TSS (Table 6.40). The four upstream stations show a downward trend for flow, while three of the five downstream stations show an increasing trend. No trends were observed in the VADEQ water quality data.

The Mood Median test results on water quality data from VADEQ station 6BSRA001.11 showed significant differences between months for conductivity, dissolved oxygen (DO), fixed solids (FS), hardness, pH, total solids (TS), and volatile solids (VS). The Mood Median test results from the DMME stations are shown in Tables 6.41 through 6.74.

Table 6.40 Trend Analysis results for DMME supplied water quality data for Straight Creek.

Constituent	Station			
	0003102	1020127	0002877	1020209
FLOW (gpm)	0.50	—	40.0	--
TEMP (C)	--	0.167	—	--
PH	--	-0.075	—	--
FE (mg/L)	--	—	-0.02	--
MN (mg/L)	--	—	-0.02	--
TSS (mg/L)	--	—	—	--
ACIDITY (mg/L)	--	—	—	--
ALKALINITY (mg/L)	--	-6.0	—	--
CONDUCTIVITY (µmhos/cm)	--	—	—	--
TDS (mg/L)	--	—	—	--
SULFATE (mg/L)	--	—	—	--

A number in station column represents the Seasonal-Kendall estimated slope.
"--": insufficient data, "—" no trend

Table 6.40 Trend Analysis results for DMME supplied water quality data for Straight Creek (continued).

Constituent	Station			
	1020237	1020241	1020226	1020225
FLOW (gpm)	12.5	-32.5	-5.0	-4.17
TEMP (C)	—	—	0.167	
PH	—	0.1	—	-0.025
FE (mg/L)	-0.033	—	-0.033	-0.025
MN (mg/L)	-0.017	—	-0.013	—
TSS (mg/L)	-0.08	—	-1.0	-0.5
ACIDITY (mg/L)	—	—	—	—
ALKALINITY (mg/L)	2.41	—	—	—
CONDUCTIVITY (µmhos/cm)	12.0	—	—	5.0
TDS (mg/L)	—	—	—	-6.33
SULFATE (mg/L)	—	—	—	—

A number in station column represents the Seasonal-Kendall estimated slope.
"--": insufficient data, "—" no trend

Table 6.41 Summary of Moods Median Test on mean monthly conductivity at VADEQ station 6BSRA001.11 on Straight Creek.

Month	Mean (µmhos/cm)	Minimum (µmhos/cm)	Maximum (µmhos/cm)	Median Groups[1]	
January	437	185	696	A	
February	698	405	901		
March	484	301	767	A	
April	457	40.1	836	A	B
May	622	404	885	A	B
June	10,214	428	20,000		
July	898	501	1,376		B
August	3,682	538	20,000		B
September	1,292	588	2,700		B
October	1,521	457	8,500		B
November	870	600	1,123		B
December	504	397	610		

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.42 Summary of Moods Median Test on mean monthly DO at VADEQ station 6BSRA001.11 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]		
January	12.7	10.63	15.06		B	C
February	12.5	11.67	12.9			C
March	11.1	9.7	11.9		B	C
April	10.8	9.78	12.19		B	C
May	9.6	8.45	10.8	A	B	
June	8.6	8.6	8.6			
July	8.8	7.23	10.02	A	B	
August	8.2	7.7	8.62	A		
September	9.3	7.99	11.5	A	B	
October	10.5	9.43	12.91		B	
November	12.4	11.31	13.37			C
December	13.4	12.2	14.62			C

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.43 Summary of Moods Median Test on mean monthly fixed solids at VADEQ station 6BSRA001.11 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	315.6	219	471	A	
February	222.0	222	222		
March	270.3	189	403	A	B
April	317.7	210	483	A	B
May	403.3	300	608	A	B
June	1,120.0	1,120	1,120		
July	560.6	340	870		B
August	1,139.5	479	1,800		B
September	674.8	370	972		B
October	630.6	277	1,008		B
November	559.8	376	686		B
December	237.0	237	237		

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.44 Summary of Moods Median Test on mean monthly hardness (mg/L AS CACO3) at VADEQ station 6BSRA001.11 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]		
January	264.6	94.9	1,500	A	B	C
February	108.0	108	108			
March	97.0	90	105	A		
April	116.6	101	172	A	B	
May	135.3	114	160		B	
June	240.0	240	240			
July	177.0	142	222			C
August	473.0	146	800		B	C
September	183.8	152	195			C
October	202.0	156	268			C
November	171.4	148	189		B	C
December	144.0	144	144			

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.45 Summary of Moods Median Test on mean monthly pH at VADEQ station 6BSRA001.11 on Straight Creek.

Month	Mean	Minimum	Maximum	Median Groups[1]	
January	7.9	7.42	8.57	A	B
February	8.0	7.87	8.22	A	B
March	8.2	7.99	8.5		B
April	7.8	7.7	8.0	A	
May	7.9	7.48	8.28	A	B
June	8.3	8.32	8.32		
July	8.1	7.8	8.36	A	B
August	7.9	7.48	8.17	A	B
September	8.2	7.88	8.45	A	B
October	8.2	7.71	8.47	A	B
November	8.3	8.13	8.37		B
December	8.0	7.91	8.11	A	B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.46 Summary of Moods Median Test on mean monthly temperature (C) at VADEQ station 6BSRA001.11 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]			
January	5.8	2.6	9.7	A	B		
February	5.4	4.9	6.2	A			
March	10.7	7.4	12.4		B		
April	12.9	8.9	18.9		B	C	
May	15.4	13.7	18.2				D
June	17.9	17.9	17.9				
July	21.6	19.4	26.5				D
August	19.2	18.1	20.9				D
September	20.2	17.3	23.4				D
October	13.8	9.4	18.3		B	C	
November	8.5	5.1	12.2	A	B		
December	5.7	4.1	7.3	A			

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.47 Summary of Moods Median Test on mean monthly total solids at VADEQ station 6BSRA001.11 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	355	258	530	A	
February	250	250	250		
March	300	212	447	A	B
April	355	246	527	A	B
May	445	335	661	A	B
June	1,320	1,320	1,320		
July	618	391	941		B
August	1,187	514	1,860		B
September	721	412	1,008		B
October	689	309	1,092		B
November	611	402	742		B
December	272	272	272		

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.48 Summary of Moods Median Test on mean monthly volatile solids at VADEQ station 6BSRA001.11 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	39.7	21.0	71.0	A	B
February	28.0	28.0	28.0		
March	30.0	23.0	44.0	A	
April	37.6	30.0	47.0	A	B
May	42.0	33.0	53.0	A	B
June	200	200	200		
July	56.9	16.0	82.0		B
August	47.5	35.0	60.0	A	B
September	46.0	34.0	76.0	A	B
October	58.3	32.0	84.0		B
November	51.0	26.0	68.0	A	B
December	35.0	35.0	35.0		

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.49 Summary of Moods Median Test on mean monthly flow at DMME MPID 0003102 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	54	1	100	A	B
February	68	15	125		B
March	113	50	225		B
April	234	45	500		B
May	113	20	250		B
June	51	0	200	A	B
July	68	2	300	A	B
August	15	5	25	A	B
September	5	0	20	A	
October	5	0	15	A	
November	49	0	200	A	B
December	91	0	150	A	B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.50 Summary of Moods Median Test on mean monthly temperature (C) at DMME MPID 1020127 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]			
January	4.5	3.0	7.0	A			
February	5.0	3.0	8.0	A			
March	7.0	4.0	11.0	A	B		
April	10.0	7.0	16.0		B	C	
May	14.0	11.0	16.0			C	
June	16.6	15.0	18.0			C	D
July	18.6	17.0	20.0				D
August	19.3	18.0	20.0				D
September	18.4	17.0	22.0				D
October	13.8	11.0	17.0			C	
November	9.8	8.0	13.0		B		
December	7.6	3.0	10.5	A	B		

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.51 Summary of Moods Median Test on mean monthly temperature (C) at DMME MPID 0002877 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	6.5	2.0	9.0	A	
February	7.3	5.0	10.0	A	
March	6.8	4.0	10.0	A	
April	9.7	8.0	11.0	A	B
May	15.7	14.0	17.0		B
June	15.3	11.0	18.0		B
July	18.5	17.0	21.0		B
August	18.5	17.0	20.0		B
September	15.5	12.0	19.0		B
October	12.3	9.0	18.0	A	B
November	8.0	4.0	12.0	A	B
December	7.0	3.0	12.0	A	B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.52 Summary of Moods Median Test on mean monthly alkalinity at DMME MPID 0002877 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	76	57	104	A	
February	124	81	176	A	B
March	81	54	116	A	
April	87	56	117	A	
May	119	16	181	A	B
June	144	101	231	A	B
July	173	116	270		B
August	204	130	345		B
September	193	104	385	A	B
October	162	146	188		B
November	154	108	217		B
December	135	65	223	A	B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.53 Summary of Moods Median Test on mean monthly conductivity at DMME MPID 0002877 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	305	180	390	A	
February	514	410	734		B
March	346	220	480	A	B
April	357	233	498	A	B
May	505	370	580		B
June	507	380	710		B
July	640	490	1,118		B
August	725	520	1,200		B
September	742	380	1,580		B
October	655	510	800		B
November	583	390	880		B
December	510	240	907	A	B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.54 Summary of Moods Median Test on mean monthly flow at DMME MPID 0002877 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	719	600	825		B
February	650	600	800		B
March	620	500	800		B
April	621	500	800		B
May	598	500	800		B
June	458	350	600	A	B
July	434	225	580	A	B
August	515	150	1,400	A	B
September	347	125	580	A	B
October	268	100	400	A	
November	388	275	600	A	B
December	583	350	900		B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.55 Summary of Moods Median Test on mean monthly TDS at DMME MPID 0002877 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups1	
January	266	182	385	A	B
February	312	195	441	A	B
March	247	188	305	A	
April	253	206	300	A	
May	357	264	432	A	B
June	355	219	544	A	B
July	398	343	521		B
August	471	342	733		B
September	440	230	918	A	B
October	406	323	511		B
November	366	276	503		B
December	321	108	630	A	B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.56 Summary of Moods Median Test on mean monthly temperature (C) at DMME MPID 1020237 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	6.4	2.0	10.0	A	
February	5.4	1.0	9.0	A	
March	7.4	3.0	12.0	A	B
April	10.3	7.0	17.0	A	B
May	15.4	12.0	18.0		B
June	15.4	11.0	18.0		B
July	17.7	13.0	21.0		B
August	18.4	15.0	20.0		B
September	15.1	11.0	19.0		B
October	12.2	9.0	17.0		B
November	6.2	2.0	11.0	A	B
December	5.6	2.0	13.0	A	

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.57 Summary of Moods Median Test on mean monthly alkalinity at DMME MPID 1020237 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	140	71	226	A	B
February	120	83	222	A	
March	115	14	325	A	B
April	135	82	246	A	B
May	174	92	310	A	B
June	160	84	324	A	B
July	197	43	510		B
August	215	137	632		B
September	232	121	674		B
October	163	127	207		B
November	179	122	354		B
December	197	82	474	A	B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.58 Summary of Moods Median Test on mean monthly flow at DMME MPID 1020237 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	594	150	2,000	A	B
February	428	200	1,000		B
March	416	300	900		B
April	379	150	600		B
May	487	300	1,200		B
June	332	225	465		B
July	278	100	400	A	B
August	197	50	400	A	
September	195	30	375	A	
October	151	40	300	A	
November	301	80	950	A	B
December	336	200	600	A	B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.59 Summary of Moods Median Test on mean monthly pH at DMME MPID 1020237 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	7.9	7.0	8.3	A	B
February	8.1	7.2	8.5	A	B
March	8.1	7.6	8.4		B
April	8.2	7.8	8.4		B
May	7.9	7.2	8.2	A	B
June	7.9	7.2	8.2	A	B
July	8.0	7.4	8.3	A	B
August	8.1	7.9	8.4	A	B
September	7.9	7.5	8.3	A	B
October	7.8	7.3	8.1	A	
November	8.0	7.2	8.5	A	B
December	8.1	7.4	8.5	A	B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.60 Summary of Moods Median Test on mean monthly temperature (C) at DMME MPID 1020241 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]		
January	5.3	2.0	8.0	A	B	
February	4.0	1.0	7.0	A		
March	8.8	4.0	13.0	A	B	
April	10.3	6.0	17.0	A	B	C
May	13.7	12.0	15.0		B	
June	15.7	13.0	18.0		B	C
July	16.7	15.0	19.0			C
August	16.0	15.0	17.0			C
September	14.0	12.0	16.0		B	C
October	14.0	13.0	15.0		B	
November	5.7	4.0	7.0	A		
December	5.3	3.0	9.0	A	B	

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.61 Summary of Moods Median Test on mean monthly alkalinity at DMME MPID 1020241 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]		
January	105.5	72.0	135	A	B	
February	87.5	74	97	A	B	
March	76.5	72	84	A		
April	93.0	78	106	A	B	
May	92.3	76	103	A	B	
June	112.0	80	128	A	B	
July	134.7	112	160		B	
August	169.7	142	188		B	C
September	176.7	134	213		B	C
October	196.7	190	208			C
November	145.0	122	180		B	C
December	122.3	87	160		B	

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.62 Summary of Moods Median Test on mean monthly conductivity at DMME MPID 1020241 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	332.5	290.0	380	A	
February	320.0	120	460	A	B
March	345.0	320	380	A	
April	380.0	360	420	A	B
May	380.0	280	460	A	B
June	433.3	300	500	A	B
July	476.7	440	510		B
August	486.7	460	540		B
September	563.3	460	630		B
October	356.0	8	620	A	B
November	470.0	410	540		B
December	413.3	340	480	A	B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.63 Summary of Moods Median Test on mean monthly Fe at DMME MPID 1020241 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	3.6	0.1	12.9	A	B
February	0.2	0.1	0.3	A	
March	0.7	0.2	1.7	A	B
April	0.2	0.1	0.2	A	
May	16.7	0.3	46		B
June	0.5	0.5	0.6		B
July	0.6	0.5	0.8		B
August	0.7	0.4	0.9		B
September	0.8	0.2	1.3	A	B
October	0.2	0.2	0.2	A	
November	0.4	0.1	0.9	A	B
December	0.2	0.1	0.3	A	

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.64 Summary of Moods Median Test on mean monthly TSS at DMME MPID 1020241 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	414.5	7.0	1,610	A	B
February	6.8	4.0	9	A	
March	32.3	12.0	52		B
April	9.7	8.0	11	A	
May	29.3	20.0	48		B
June	25.3	19.0	29		B
July	17.7	4.0	33	A	B
August	15.3	4.0	33	A	B
September	40.0	11.0	82	A	B
October	4.3	4.0	5	A	
November	11.3	5.0	20	A	B
December	4.3	4.0	5	A	

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.65 Summary of Moods Median Test on mean monthly alkalinity at DMME MPID 1020226 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]			
January	97	72	135	A	B	C	
February	92	69	124	A	B		
March	82	71	118	A			
April	90	73	110	A	B		
May	102	76	118		B		
June	127	80	172		B	C	D
July	143	112	163			C	
August	167	130	196			C	D
September	182	126	222			C	D
October	197	162	217				D
November	153	102	192			C	D
December	123	87	160		B	C	

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.66 Summary of Moods Median Test on mean monthly temperature (C) at DMME MPID 1020226 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]			
January	5.9	2.0	10.0	A			
February	5.8	1.0	10.0	A	B		
March	7.6	3.0	13.0	A	B		
April	10.4	6.0	17.0		B		
May	14.6	12.0	18.0			C	
June	15.0	11.0	18.0		B	C	D
July	17.0	15.0	19.0			C	D
August	16.9	15.0	18.0				D
September	14.9	12.0	19.0			C	D
October	13.7	11.0	18.0		B	C	
November	8.4	4.0	14.0	A	B		
December	6.4	3.0	13.0	A	B		

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.67 Summary of Moods Median Test on mean monthly conductivity at DMME MPID 1020226 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	380	240	540	A	B
February	374	120	491	A	B
March	379	320	460	A	B
April	377	280	434	A	
May	398	280	460	A	B
June	464	300	700	A	B
July	490	440	530		B
August	537	390	690		B
September	596	460	800		B
October	606	440	914		B
November	532	380	737		B
December	435	340	668	A	B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.68 Summary of Moods Median Test on mean monthly flow at DMME MPID 1020226 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	203	50	800		B
February	139	75	400		B
March	147	75	400		B
April	87	30	100		B
May	172	20	800		B
June	96	40	300		B
July	84	25	280	A	B
August	43	20	75	A	B
September	43	10	75	A	B
October	33	10	75	A	
November	114	20	600	A	B
December	96	35	275		B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.69 Summary of Moods Median Test on mean monthly TDS at DMME MPID 1020226 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	285	136	542	A	B
February	258	187	314	A	
March	266	199	346	A	
April	281	235	338	A	B
May	318	203	439	A	B
June	341	212	450	A	B
July	341	265	420		B
August	359	257	475		B
September	403	290	668		B
October	427	305	629		B
November	400	249	608		B
December	415	204	1175	A	B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.70 Summary of Moods Median Test on mean monthly temperature (C) at DMME MPID 1020225 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]			
January	5.9	1.0	10.0	A			
February	6.1	1.0	11.0	A			
March	7.8	3.0	13.0	A	B		
April	10.7	6.0	19.0		B		
May	14.6	13.0	18.0			C	
June	15.6	10.0	18.0			C	D
July	17.7	16.0	20.0				D
August	17.8	17.0	20.0				D
September	15.3	13.0	19.0			C	D
October	13.2	10.0	17.0		B	C	
November	8.0	4.0	13.0	A	B		
December	6.0	2.0	13.0	A	B		

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.71 Summary of Moods Median Test on mean monthly alkalinity at DMME MPID 1020225 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	104	72	264	A	B
February	77	58	100	A	B
March	69	59	81	A	
April	76	64	88	A	
May	87	72	109	A	B
June	102	76	127		B
July	118	110	124		B
August	133	107	228		B
September	134	112	167		B
October	165	120	354		B
November	120	84	168		B
December	102	82	123		B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.72 Summary of Moods Median Test on mean monthly conductivity at DMME MPID 1020225 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	336	260	430	A	B
February	340	120	450	A	B
March	340	270	440	A	
April	354	260	400	A	
May	363	280	478	A	B
June	438	300	580	A	B
July	436	350	484		B
August	489	420	600		B
September	514	410	620		B
October	532	400	700		B
November	460	360	638	A	B
December	418	310	569	A	B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.73 Summary of Moods Median Test on mean monthly flow at DMME MPID 1020225 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]	
January	164	30	600		B
February	118	50	350		B
March	111	50	300		B
April	72	40	100		B
May	132	30	600		B
June	74	30	275		B
July	54	20	150		B
August	33	15	50	A	B
September	26	5	50	A	B
October	19	5	40	A	
November	76	5	400	A	B
December	75	30	250		B

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

Table 6.74 Summary of Moods Median Test on mean monthly TDS at DMME MPID 1020225 on Straight Creek.

Month	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Median Groups[1]		
January	273	55	495	A	B	C
February	229	150	287	A		
March	256	185	416	A	B	
April	243	186	290	A		
May	283	180	470	A	B	C
June	293	196	363	A	B	C
July	277	163	350	A	B	
August	314	265	366		B	
September	325	268	440		B	C
October	385	279	505			C
November	335	251	409		B	C
December	295	199	403	A	B	C

[1]Months with the same median group letter are not significantly different from each other at the 95% level of significance.

This page intentionally left blank.

7. TMDL ENDPOINT: STRESSOR IDENTIFICATION

7.1 Stressor Identification

There are no water quality standards or recommended screening levels for many of the water quality parameters sampled in the Straight Creek watershed. In order to assess the potential impact of water quality on the macroinvertebrate population in Straight Creek, a suitable watershed was selected for comparison. The McClure River is a fourth order stream in the same ecoregion as Straight Creek and there are mining related land uses in the watershed. Recent biological monitoring at VADEQ station 6AMCR000.55 indicates a healthy macroinvertebrate population. Therefore, for water quality parameters without established standards or screening levels, the 90th percentile for the parameters available from the McClure River (6AMCR000.20) were used to evaluate the water quality data in this stressor analysis. When a parameter exceeded the 90th percentile more than 10% of the time it was considered excessive, and a scatter graph is shown for the parameter at that monitoring station. Depending on the habitat and benthic metrics, additional chemical evidence, and references documenting potential problems for aquatic life, a parameter with excessive values may be considered a possible or probable stressor. In addition summary graphs depicting the median values at multiple VADEQ and DMME MPIDs for each parameter that had more than nine data points are also shown. The presence of nine values was selected as a cut off in order to avoid using data from stations that were not sampled during different seasons of the year or different flow regimes of Straight Creek. However, all data collected on Straight Creek was carefully reviewed to ensure it was consistent with expected values and to document any extreme values. The monitoring data supplied by DMME was collected from 1/1995 to 12/2003 and there was considerable variation in the amount of data collected at each monitoring site. For example, data at some sites was collected very early in the sampling period and at other sites near the end of the sampling period. In the graphs that follow the entire sampling period is reported to show when the data was collected and to compare values between stations. Table 7.1 shows the 90th percentile values used as screening values from the McClure River (6AMCR000.20) data. Graphs for parameters with more than one data point and less than nine are shown in Appendix C. The monitoring sites are ordered from downstream to upstream in each stressor section.

Table 7.1 McClure River (6AMCR000.20) 90th percentile screening values.

Parameter	90th Percentile
Conductivity (μmhos/cm)	800
Total dissolved solids (mg/L)	525
Total suspended solids, (mg/L)	25
Sulfate (mg/L)	150
Alkalinity (mg/L)	200
Iron sediment (mg/Kg)	23,947
Manganese sediment (mg/Kg)	897
Selenium sediment (mg/Kg)	1.0
Nitrate-nitrogen (mg/L)	0.41
BOD_5 (mg/L)	2.0
COD (mg/L)	12.5
Volatile solids (mg/L)	68
Volatile suspended solids (mg/L)	3.4
Turbidity (FORMAZIN TU)	28
Total iron (mg/L)	1.45
Total manganese (mg/L)	0.10*

*0.10 mg/L was used because this value represents the minimum detection value in the majority of the available data.

TMDLs must be developed for a specific pollutant(s). Benthic assessments are very good at determining if a particular stream segment is impaired or not but they usually do not provide enough information to determine the cause(s) of the impairment. The process outlined in the Stressor Identification Guidance Document (EPA, 2000) was used to separately identify the most probable stressor(s) for Straight Creek. A list of candidate causes was developed from published literature, VADEQ, and DMME staff input. Chemical and physical monitoring data provided evidence to support or eliminate potential stressors. Individual metrics for the biological and habitat evaluation were used to determine if there were links to a specific stressor(s). Land use data as well as a visual assessment of conditions along the stream provided additional information to eliminate or support candidate stressors. The potential stressors are: sediment, toxics, low dissolved oxygen, nutrients, pH, metals, conductivity, temperature, and organic matter.

The results of the stressor analysis for Straight Creek are divided into three categories:

Non-Stressors: Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors. Table 7.2 lists the parameters and where they are located in the document.

Possible Stressors: Those stressors with data indicating possible links, but inconclusive data, were considered to be possible stressors. Table 7.7 lists the parameters and where they are located in the document.

Most Probable Stressor: The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s). Table 7.10 lists the parameters and where they are located in the document.

7.2 Non-Stressors

Table 7.2 Non-Stressors in Straight Creek.

Parameter	Location in Document
Dissolved oxygen	Section 7.2.1
Temperature	Section 7.2.2
Nutrients	Section 7.2.3
Ammonia	Section 7.2.4
Chloride	Section 7.2.4
Sediment organics[1]	Section 7.2.4 & Appendix C, Table C.1
Sediment pesticides	Section 7.2.4 & Appendix C, Table C.2
Sediment metals[2]	Section 7.2.5
Total & Dissolved metals	Section 7.2.5

[1]except as noted in section 1.3.1, [2]except as noted in section 1.3.4

There is always a possibility that conditions in the watershed, available data, and the understanding of the natural processes change more than anticipated by the TMDL. If additional monitoring shows that different most probable stressor(s) exist or water quality target(s) are protective of water quality standards, then the Commonwealth will make use of the option to refine the TMDLs for re-submittal to EPA for approval.

7.2.1 Low dissolved oxygen

Dissolved oxygen (DO) concentrations remained well above the water quality standard at the VADEQ monitoring stations. Median values for three VADEQ monitoring stations are shown in Figure 7.1. In addition, there were no low DO concentrations in the three measurements made by ECI at three sites on Straight Creek. Low DO concentration is considered a non-stressor.

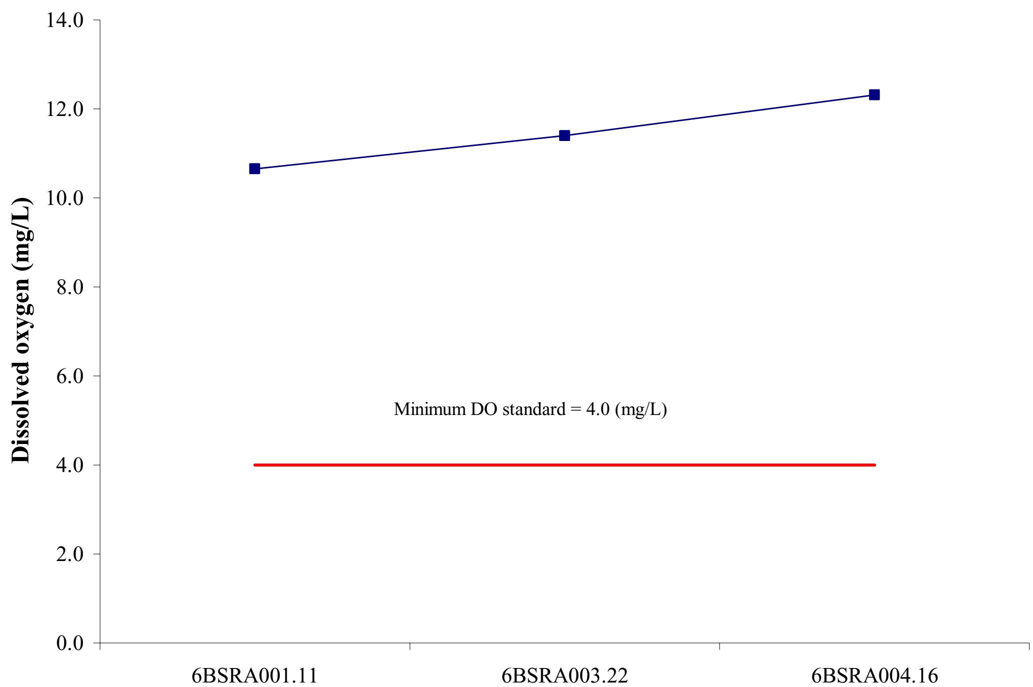

Figure 7.1 Median DO concentrations at VADEQ monitoring stations on Straight Creek.

7.2.2 Temperature

The maximum temperature recorded in Straight Creek was at VADEQ station 6BSRA001.11 (26.5^{o}C), which is well below the state standard of 31^{o}C for the mountain zone waters. Median values for three VADEQ monitoring stations are shown in Figure 7.2. The nine temperature measurements made by ECI were below the state standard. Temperature measurements at the seven DMME permitted monitoring sites were also below the state standard; median values are shown in Figure 7.3. Temperature is considered a non-stressor.

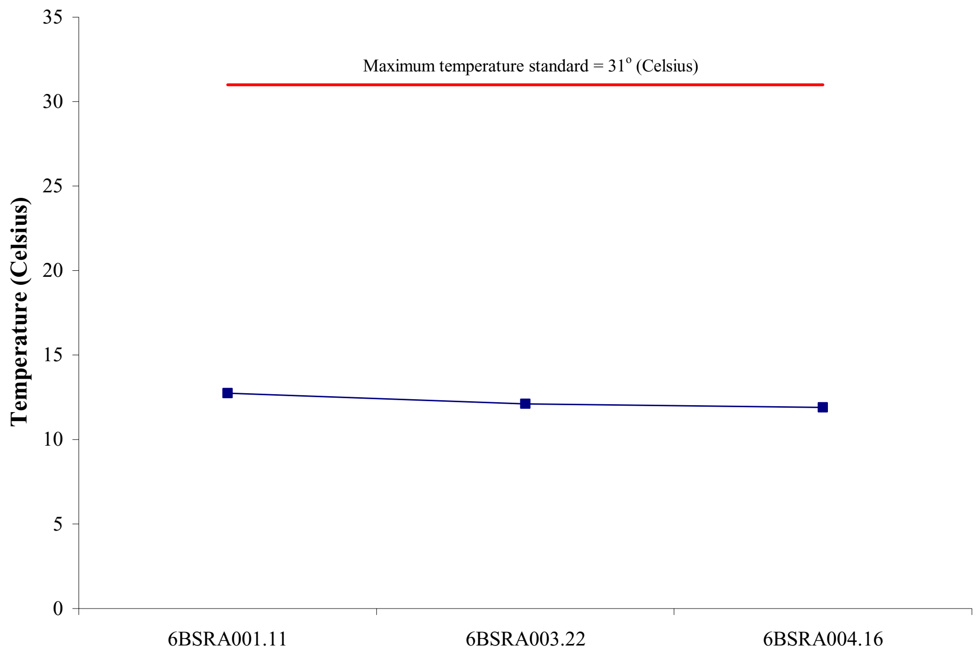

Figure 7.2 Median temperature measurements at VADEQ stations on Straight Creek.

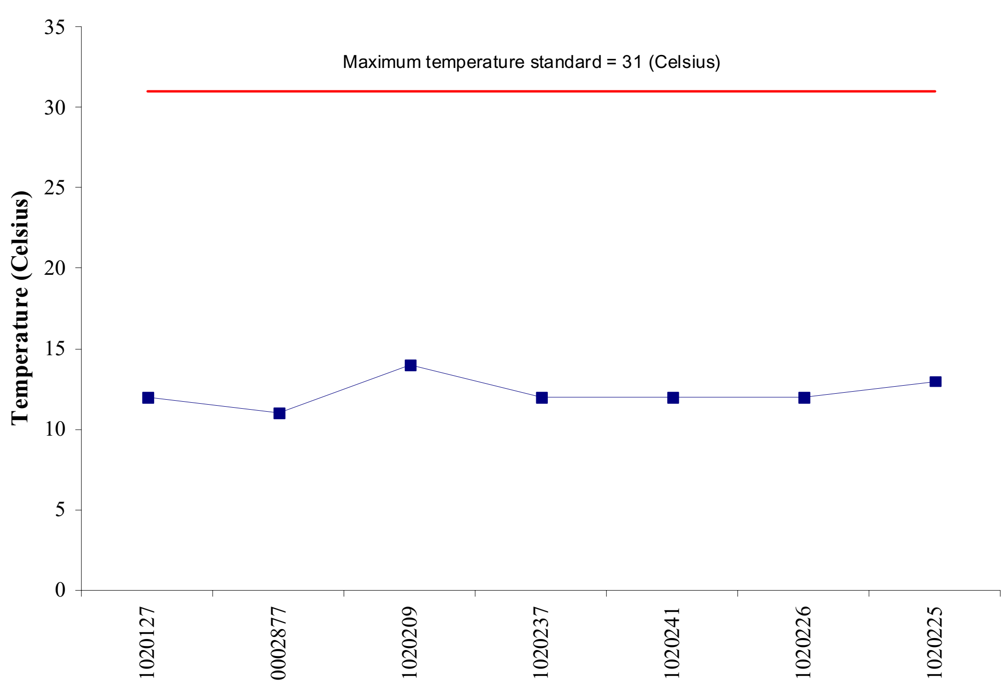

Figure 7.3 Median temperature measurements at DMME MPIDs on Straight Creek.

7.2.3 Nutrients

Median TP concentrations were below the VADEQ assessment screening value of 0.2 mg/L at all of the VADEQ stations (Figure 7.4). Only two values out of 49 samples at VADEQ station 6BSRA001.11 exceeded the screening value.

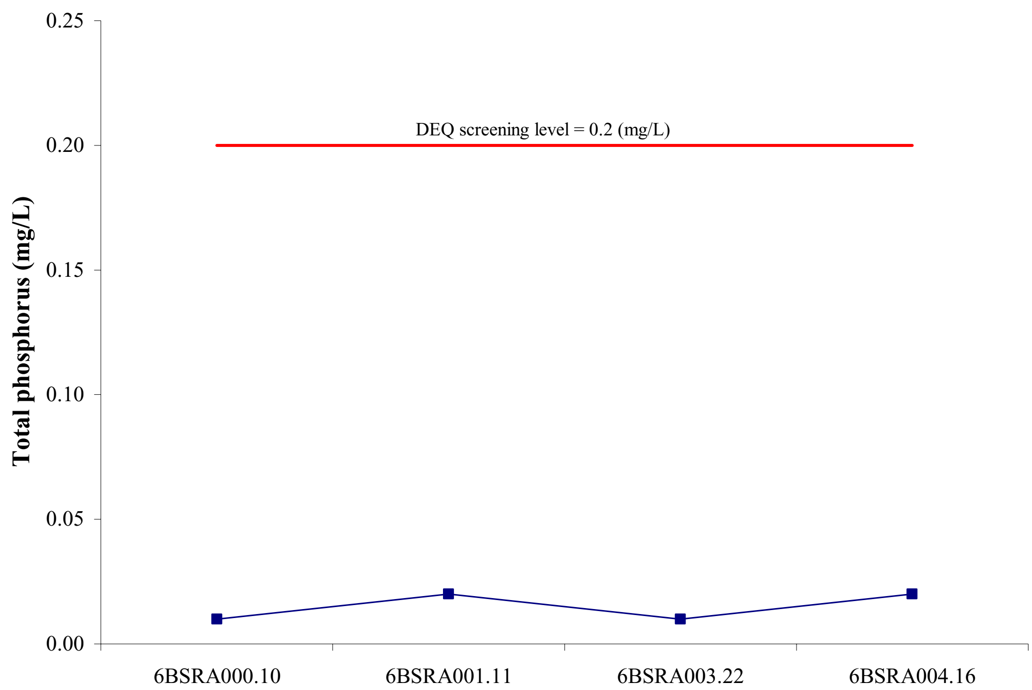

Figure 7.4 Median TP concentrations at VADEQ stations on Straight Creek.

Nitrate nitrogen (NO_3-N) concentrations exceeded the 90th percentile value of 0.41 mg/L in more than 10% of the samples collected at three VADEQ monitoring stations (Figures 7.5 through 7.7). Median NO_3-N concentrations also exceeded the 90th percentile value of 0.41 mg/L at these three VADEQ stations (Figure 7.8). A more thorough examination of nutrients was performed to try and determine the potential for eutrophication from the existing data at VADEQ station 6BSRA001.11. The criteria used can be found in Water quality assessment: A screening procedure for toxic and conventional pollutants in surface and ground water (Mills et al., 1985). The results indicated that TP was the most limiting nutrient 97% of the time. However, TP concentrations exceeded the PLE threshold during the algal growing season only 10% of the time. Therefore, nutrients are considered non-stressors.

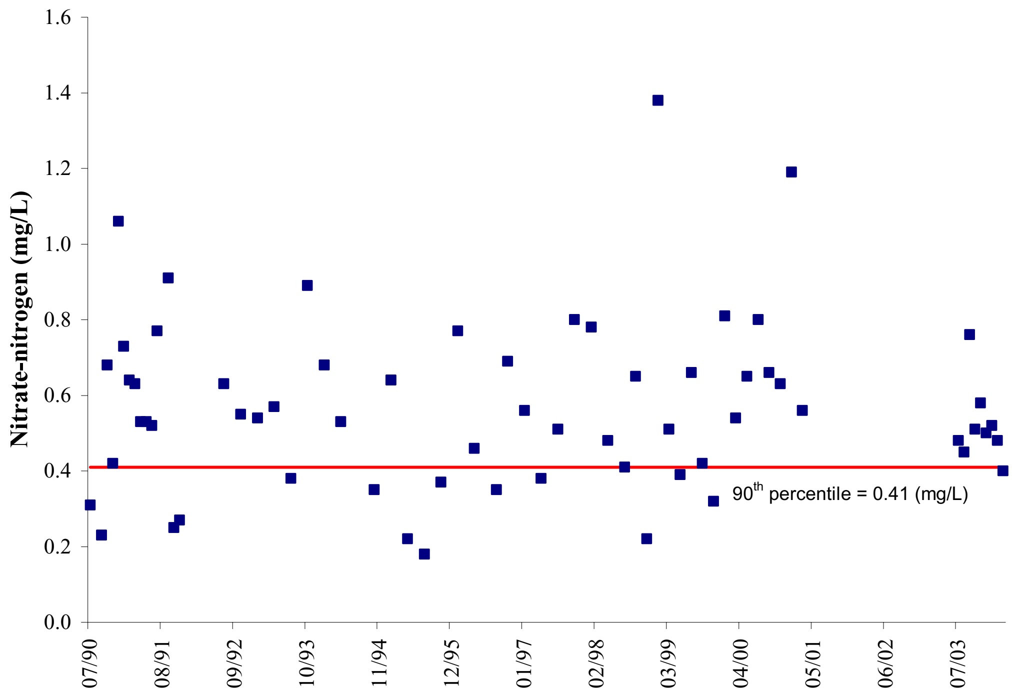

Figure 7.5 NO_3-N concentrations at VADEQ station 6BSRA001.11.

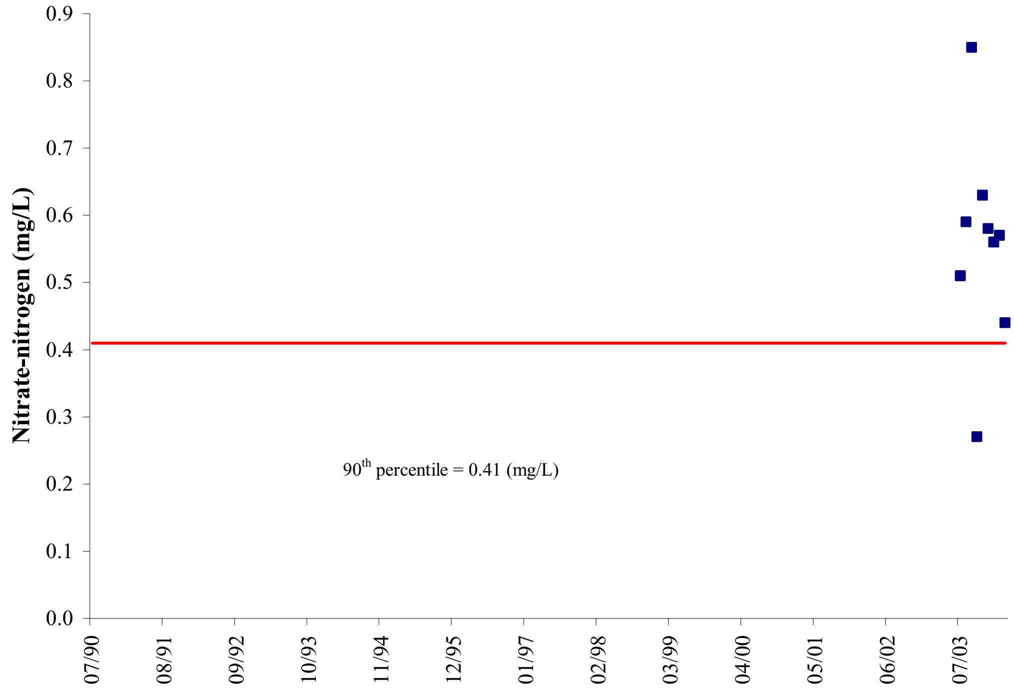

Figure 7.6 NO_3-N concentrations at VADEQ station 6BSRA003.22.

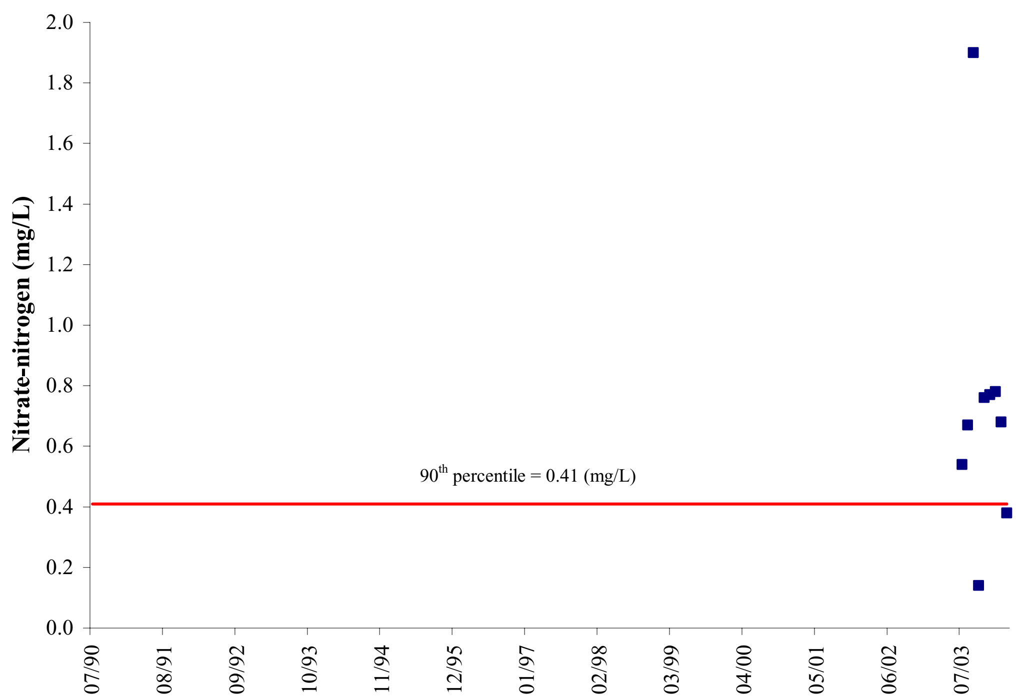

Figure 7.7 NO_3-N concentrations at VADEQ station 6BSRA004.16.

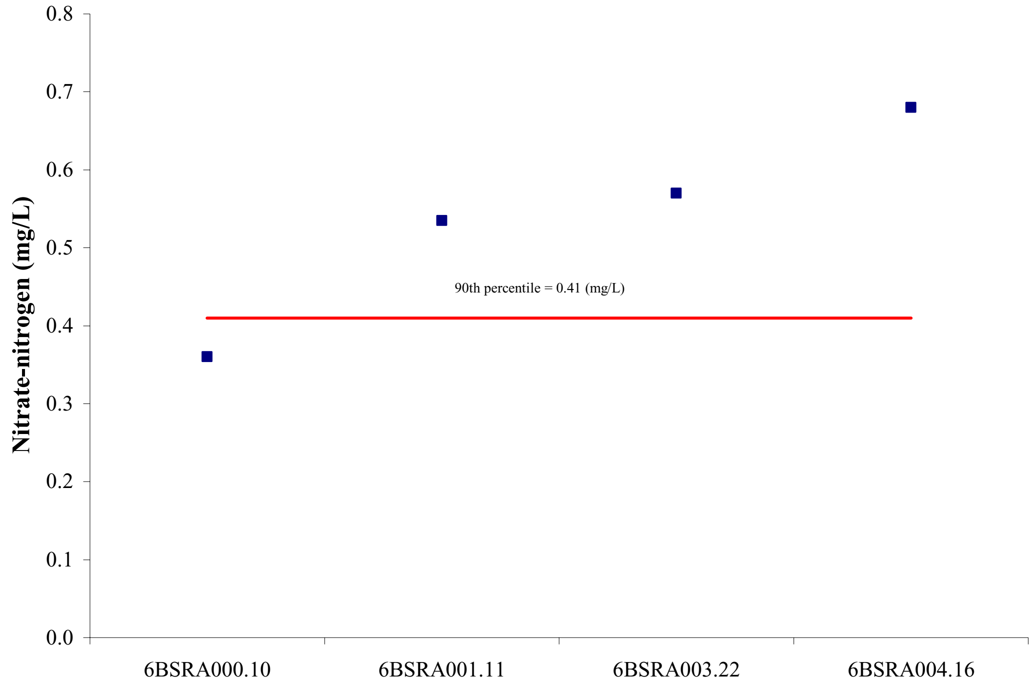

Figure 7.8 Median NO_3-N concentrations at VADEQ stations on Straight Creek.

7.2.4 Toxics

Most of the available total ammonia (NH_3/NH_4) data was below the detection level at VADEQ station 6BSRA001.11. The median value for this station is 0.06 mg/L. All ammonia values were well below the chronic water quality standard, which is temperature and pH dependent, at VADEQ stations 6BSRA001.11 and 6BSRA003.22 (Figures 7.9 and 7.10). Chloride values at 6BSRA001.11 are all below 230 mg/L, which is EPA's chronic water quality criterion (Figure 7.11). PCB's, organics and pesticides were collected at VADEQ stations 6BSRA001.11 and 6BSRA001.34 on June 18, 2002 and August 13, 1997, respectively, as part of VADEQ's fish tissue and sediment monitoring program. All sediment values at these two monitoring stations were below the established PEC (MacDonald et al., 2000) values. Toxic levels of these parameters in fish were low, with the exception of total PCBs. The state standard is 54 ppb and red-breasted sunfish had values of 105 ppb. The Virginia Department of Health has not issued a fish consumption advisory for Straight Creek. Total PCB levels in sediment samples were extremely low. This data can be found in Tables C.1 and C.2 in Appendix C.

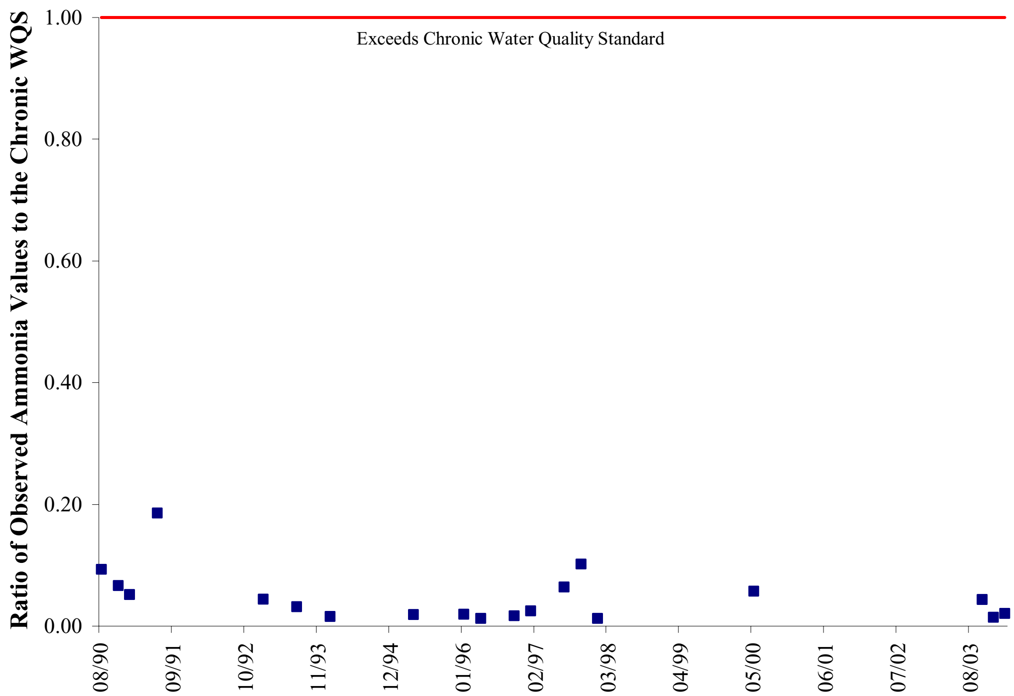

Figure 7.9 Ammonia ratio of observed values to the chronic water quality standard at VADEQ 6BSRA001.11.

Figure 7.10 Ammonia ratio of observed values to the chronic water quality standard at VADEQ 6BSRA003.22.

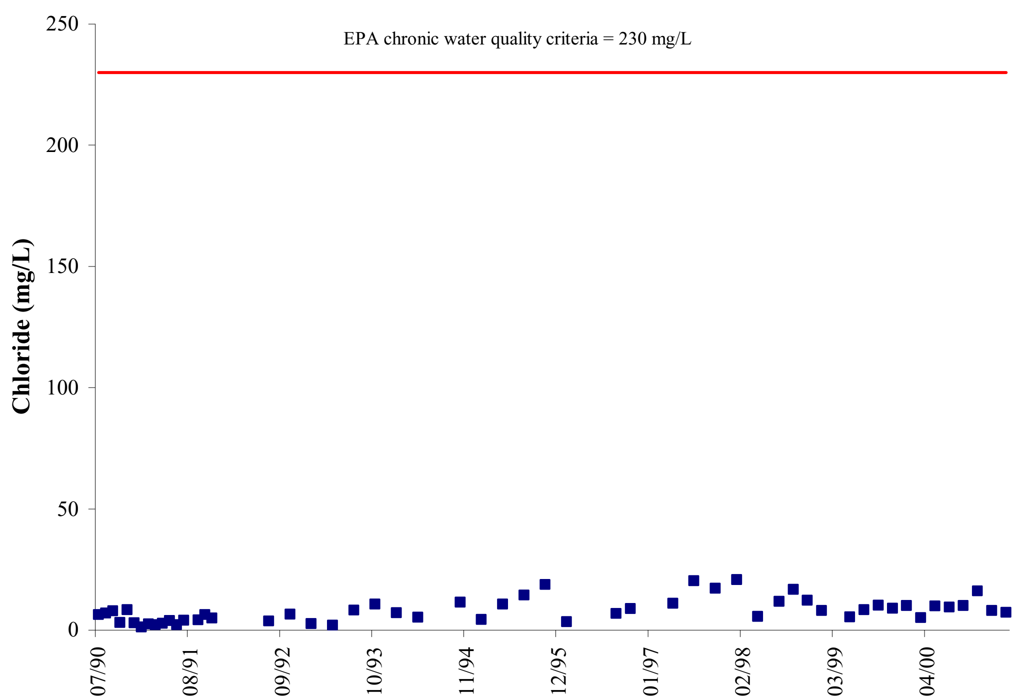

Figure 7.11 Chloride concentrations at VADEQ station 6BSRA001.11.

7.2.5 Metals

Total iron (Fe) is measured at DMME MPIDs. The toxic impacts from total iron are not well known because of the complexes iron forms with other compounds. A study by Soucek (2001) noted the potential for iron precipitates to have a smothering effect on benthic organisms. Total Fe concentrations were low and Straight Creek did not exceed the 90th percentile value of 1.45 mg/L in more than 10% of the samples collected at any DMME MPID. Median values for Straight Creek at all seven DMME MPIDs are shown in Figure 7.12.

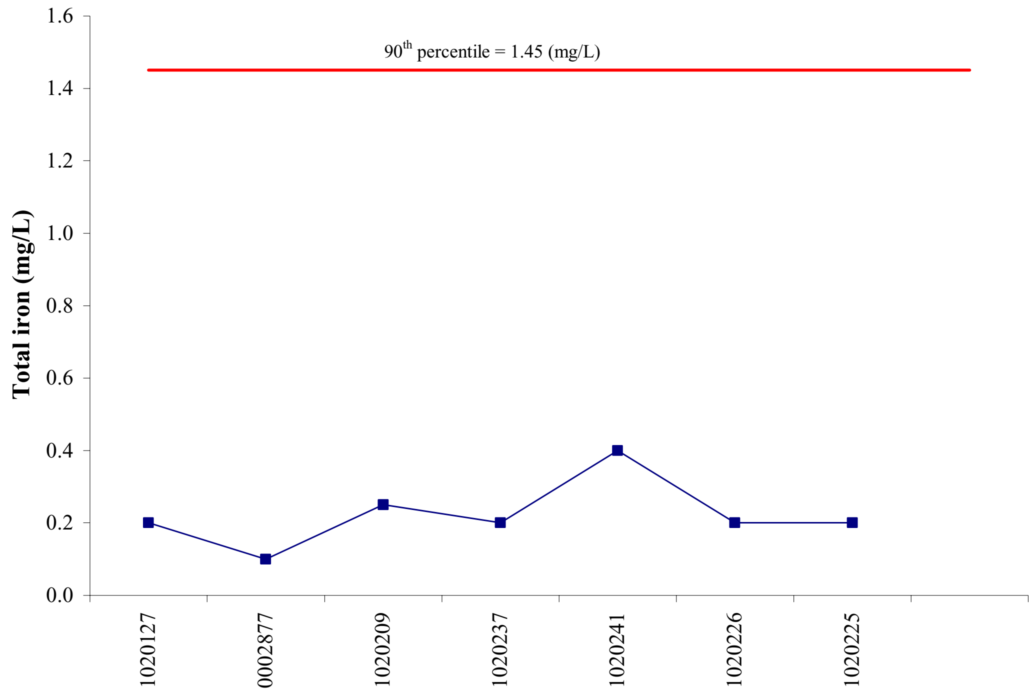

Figure 7.12 Median total Fe concentrations at DMME MPIDs on Straight Creek.

Water column dissolved metals were sampled by the VADEQ at 6BSRA001.11 on two occasions and the results were either at the minimum detection level or below the appropriate water quality standard (Table 7.3).

Table 7.3 Dissolved metals at VADEQ stations on Straight Creek (µg/L).

Metal	Date	6BSRA000.11	6BSRA000.54	6BSRA001.10	6BSRA001.11
	10/31/2000	4.8	3.45	16.2	
Aluminum	8/6/2003				148
	Standard	NA	NA	NA	NA
	10/31/2000	0.11	0.12	0.14	
Antimony	8/6/2003				0.17
	Standard	NA	NA	NA	NA
	10/31/2000	0.21	0.2	0.23	
Arsenic	8/6/2003				0.33
	Standard	NA	NA	NA	NA
	10/31/2000				
Barium	8/6/2003				35
	Standard	NA	NA	NA	NA
	10/31/2000	0.24	0.24	0.56	
Cadmium	8/6/2003				
	Standard	8.39	6.47	6.29	7.04
	10/31/2000				
Chromium	8/6/2003				1.11
	Standard	3,017	2,496.8	2,446.9	2,655.6
	10/31/2000	0.49	0.53	0.55	
Copper	8/6/2003				1.18
	Standard	33.46	26.92	26.3	28.9
	10/31/2000	6.28	2.35	4.41	
Manganese	8/6/2003				93
	Standard	NA	NA	NA	NA
	10/31/2000	0.55	0.61	1.15	
Nickel	8/6/2003				5.66
	Standard	323.3	265.9	260.4	283.4
	10/31/2000				
Selenium	8/6/2003				1.5
	Standard	NA	NA	NA	NA
	10/31/2000				
Zinc	8/6/2003				1.95
	Standard	207.2	170.4	166.9	181.6

NA - Virginia has no water quality standard

Total manganese (Mn) concentrations were high throughout Straight Creek relative to the 90th percentile value of 0.10 mg/L. Five of the seven DMME MPIDs had concentrations that exceeded 0.10 mg/L in more than 10% of the samples collected (Table 7.4 and Figures 7.13 through 7.17). There were two extreme values reported at DMME MPID 1020127 (9.0 mg/L) and DMME MPID 1020237 (1.0 mg/L). Median total Mn concentrations are shown in Figure 7.18. DMME MPID 1020127 had a median Mn concentration of 0.3 mg/L, which is above the 90th percentile concentration of 0.1 mg/L. Total Mn was sampled six times at the VADEQ station 6BSRA001.11 and none of the concentrations exceeded the 90th percentile value. There was one exceedance in the Mn data collected by ECI at station SC, river mile 0.19 (0.12 mg/L). Dissolved Mn was measured at four VADEQ stations (Table 7.3). There was one extreme value of 93 mg/L reported at VADEQ station 6BSRA001.11. There are no known or established toxic levels for Mn and aquatic life so it is considered a non-stressor.

Table 7.4 DMME MPIDs with excessive total Mn concentrations.

MPID	River Mile	%Exceedances	Range (mg/L)
1020127	3.26	21	0.10 – 9.00
1020209	5.32	67	0.10 – 0.40
1020237	5.37	18	0.10 – 1.00
1020241	5.57	22	0.10 – 0.50
1020226	5.64	18	0.10 – 0.50

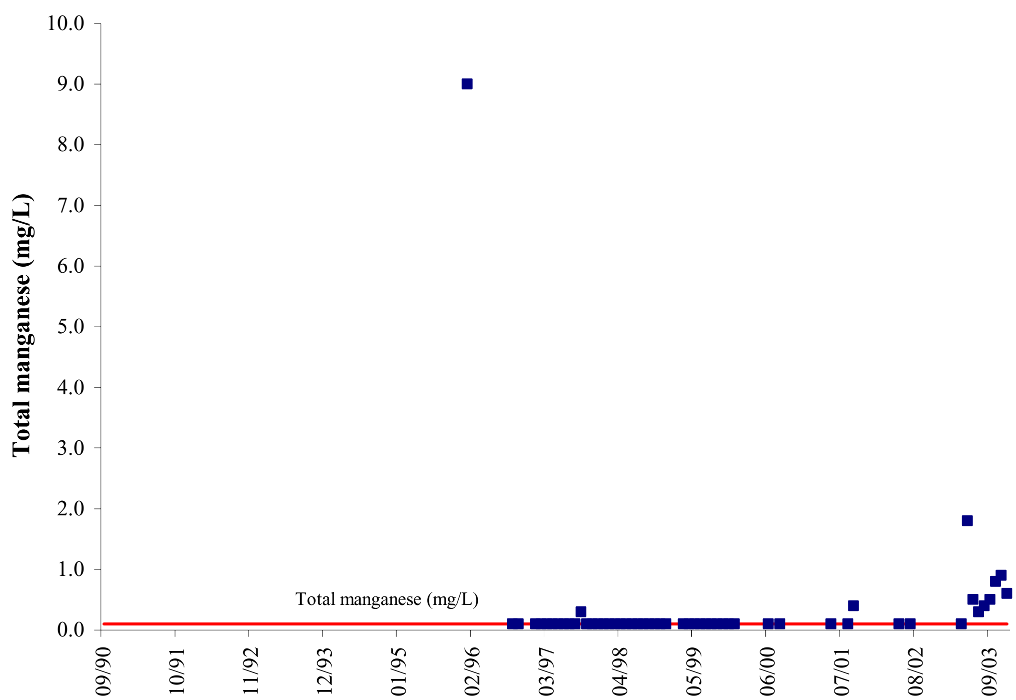

Figure 7.13 Total Mn concentrations at DMME MPID 1020127.

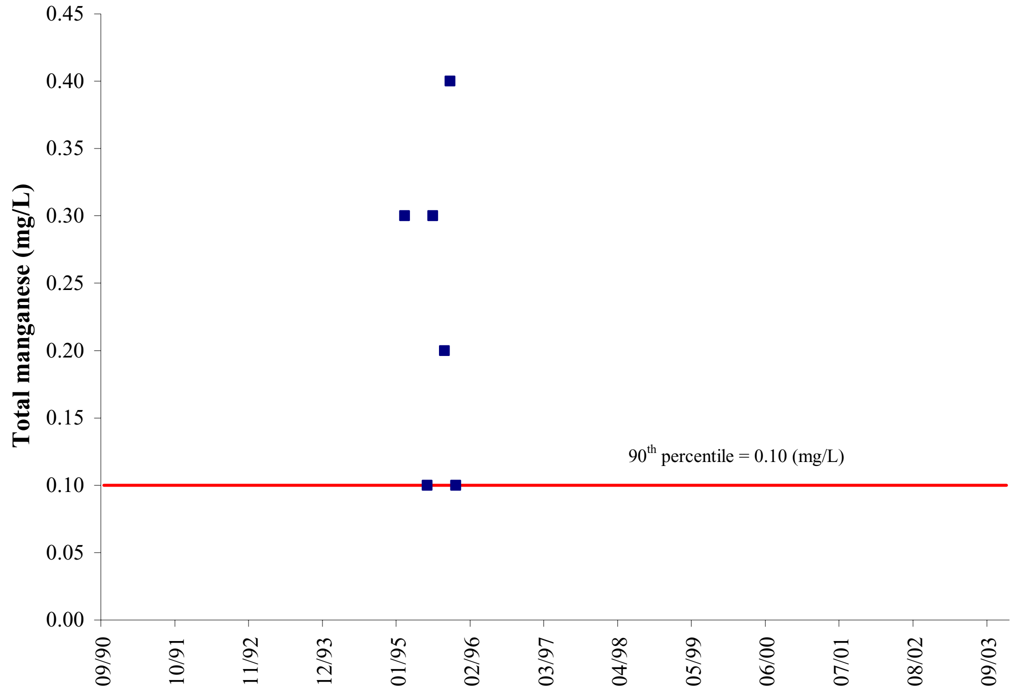

Figure 7.14 Total Mn concentrations at DMME MPID 1020209.

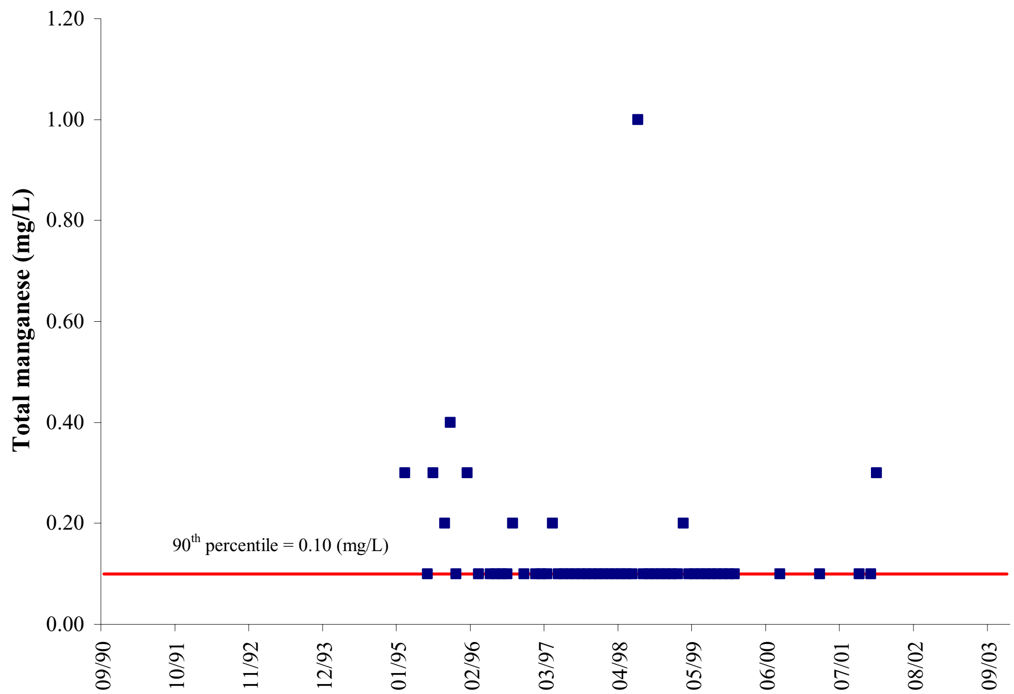

Figure 7.15 Total Mn concentrations at DMME MPID 1020237.

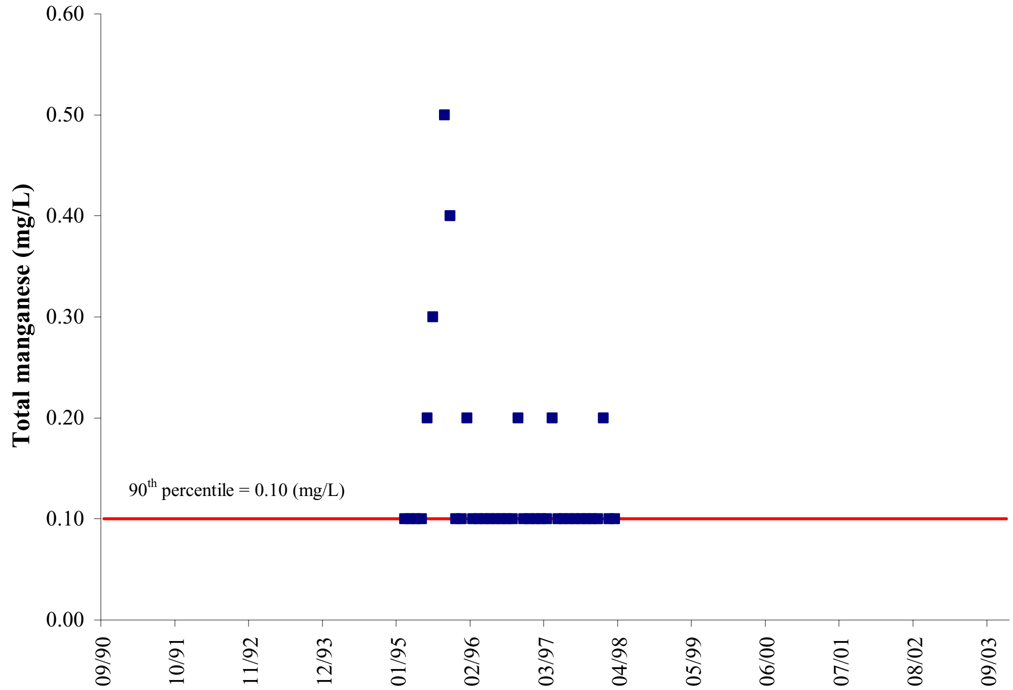

Figure 7.16 Total Mn concentrations at DMME MPID 1020241.

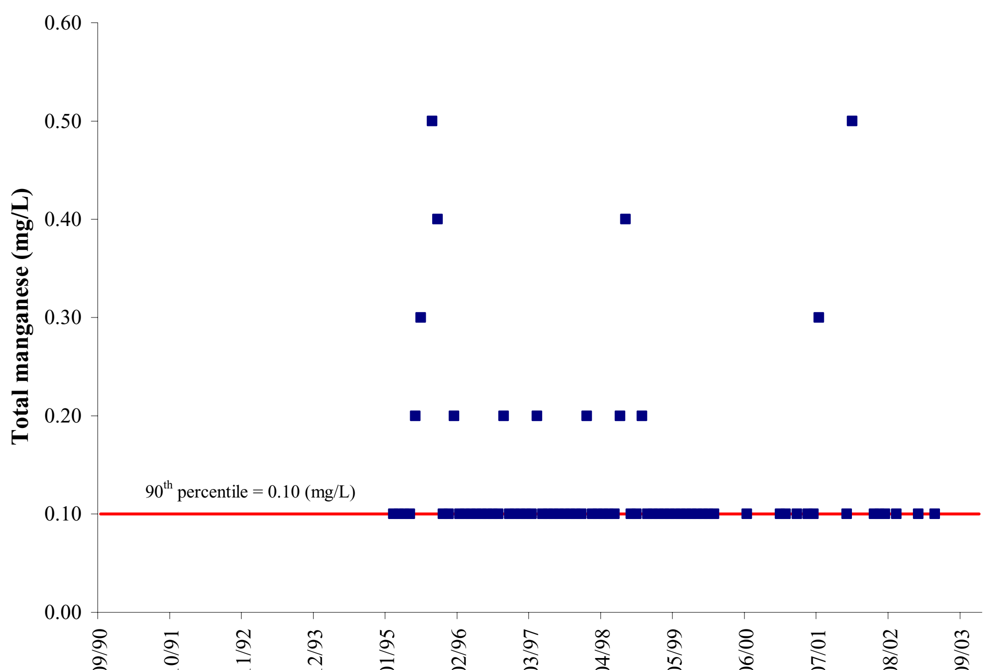

Figure 7.17 Total Mn concentrations at DMME MPID 1020226.

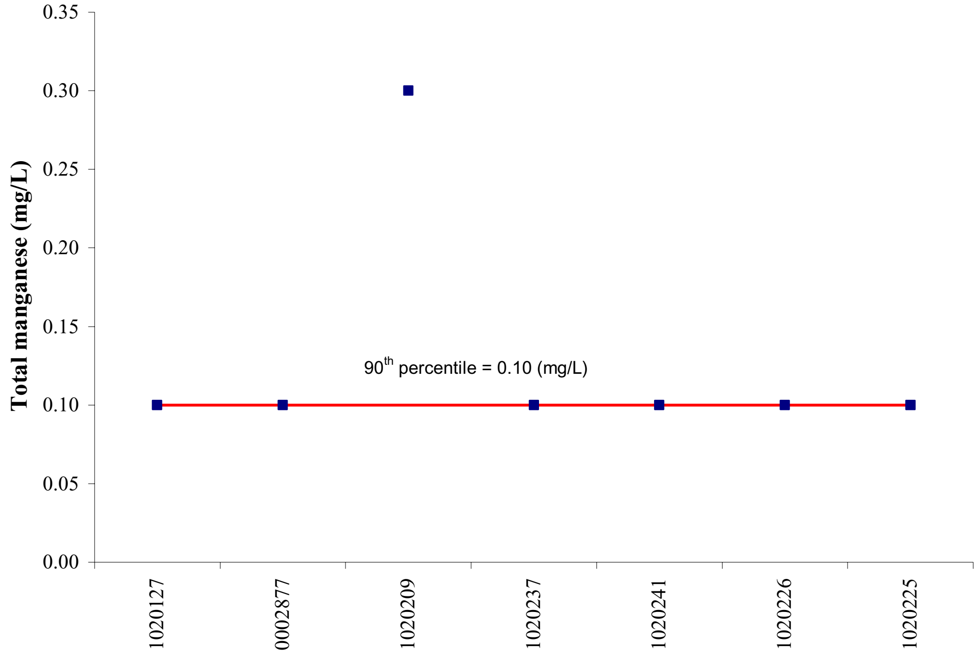

Figure 7.18 Median total Mn concentrations at DMME MPIDs on Straight Creek.

VADEQ sediment sampling indicated metals values were below the PEC values (Table 7.5), with the exception of nickel (discussed in section 7.3.4). Fish tissue and sediment metals were collected at VADEQ stations 6BSRA001.11 and 6BSRA001.34 on June 18, 2002 and August 13, 1997 respectively. No values for sediment metals exceeded PEC levels for these samples and levels were low in fish tissue as well. This sediment data is shown in Table 7.6. Baetidae, a family of mayflies, is extremely sensitive to metal pollutants and this family comprised four percent of the total assemblage from all of the benthic monitoring stations on Straight Creek.

Table 7.5 Sediment metals at VADEQ station 6BSRA001.11.

Metal (n)	Median (mg/kg)	Range (mg/kg)	PEC (mg/kg)
Aluminum (7)	10,300	4,480 – 15,600	NA
Arsenic (7)	6.70	5 – 12	33
Antimony (2)	9.0	7 – 11	NA
Beryllium (1)	NA	1.0	NA
Chromium (10)	14.85	9 – 20	111
Copper (10)	26.65	16 – 47.7	149
Iron (7)	26,500	19,800 – 48,900	NA
Lead (10)	26.35	10 – 43	128
Manganese (7)	756	452 – 1,630	NA
Nickel (10)	43.0	19.0 – 64.5	48.6
Selenium (5)	1.7	1.0 – 16.0	NA
Zinc (10)	179.00	72 – 231	459

NA - No value is available.

Table 7.6 Special study sediment metals at VADEQ stations on Straight Creek.

Parameter	PEC (mg/kg)	6BSRA001.34	6BSRA001.11
Aluminum	NA	0.19	3.6
Antimony	NA	<0.5	<0.5
Arsenic	33	5.4	7.8
Cadmium	4.98	0.15	0.31
Chromium	111	4.4	12
Copper	149	11	32
Lead	128	11	25
Mercury	1.06	0.1	0.086
Nickel	48.6	2.3	24
Selenium	NA		<0.5
Silver[1]	2.6	0.029	<0.02
Thallium	NA		<0.3
Zinc	459		84

[1] Virginia 99th percentile

7.3 Possible Stressors

Table 7.7 Possible Stressors in Straight Creek.

Parameter	Location in Document
Methylnapthelene, 2-	Section 7.3.1
Sulfate	Section 7.3.2
pH & alkalinity	Section 7.3.3
Nickel	Section 7.3.4
Organic matter	Section 7.3.5

7.3.1 Methylnapthalene, 2-

In the absence of a PEC value, Virginia has 99th percentile values for several parameters. The Virginia 99th percentile value for methylnapthalene, 2- is 83.0 µg/kg. A sediment sample collected on June 18, 2002 at VADEQ Station 6BSRA001.11 was 511.22 µg/kg. In the absence of sediment toxicity data confirming whether methylnaphthalene, -2 is bioavailable or not, it is considered a possible stressor.

7.3.2 Sulfate

Sulfate (SO_4) concentrations were excessive at six of the seven DMME MPIDs and at VADEQ station 6BSRA001.11 (Table 7.8 and Figures 7.19 through 7.25). Median SO_4 concentrations for all of the DMME MPIDs are shown in Figure 7.26. The median SO_4 concentration at VADMDLR MPID 1020127 exceeded the 90th percentile sulfate value of 150 mg/L. This site is the furthest downstream of the seven DMME MPIDs and is located at river mile 3.26, one half mile downstream of the Gin Creek confluence. All three samples collected by ECI at station SB (river mile 2.40) were above the 90th percentile value and two of the three samples collected at station SC (river mile 0.19) also exceeded the 90th percentile. The EPA used an SO_4 value of 1,000 mg/L as an indicator of impaired macroinvertebrate communities in mid-Atlantic highland streams (Klemm et al., 2001). DMME MPID 1020127 had six SO_4 values above 1,000 mg/L between May and December of 2003. Other studies note that SO_4 is a reliable indicator of mining activity and is often linked to depressed benthic health but, by itself, has not been shown to actually cause a reduction in the health of benthic communities (Merricks, 2003). However, large fluctuations in TDS can depress the health of benthic communities and sulfate is a component of TDS. Therefore, sulfate is considered a possible stressor.

Table 7.8 VADEQ stations and DMME MPIDs with excessive SO_4 concentrations.

MPID or VADEQ Station	River Mile	%Exceedances	Range (mg/L)
6BSRA001.11	1.11	66	71 – 500
1020127	3.26	51	8 – 2,132
0002877	4.87	25	42 – 215
1020209	5.32	17	64 – 177
1020237	5.37	46	35 – 530
1020226	5.64	16	38 – 258
1020225	6.06	12	27 – 225

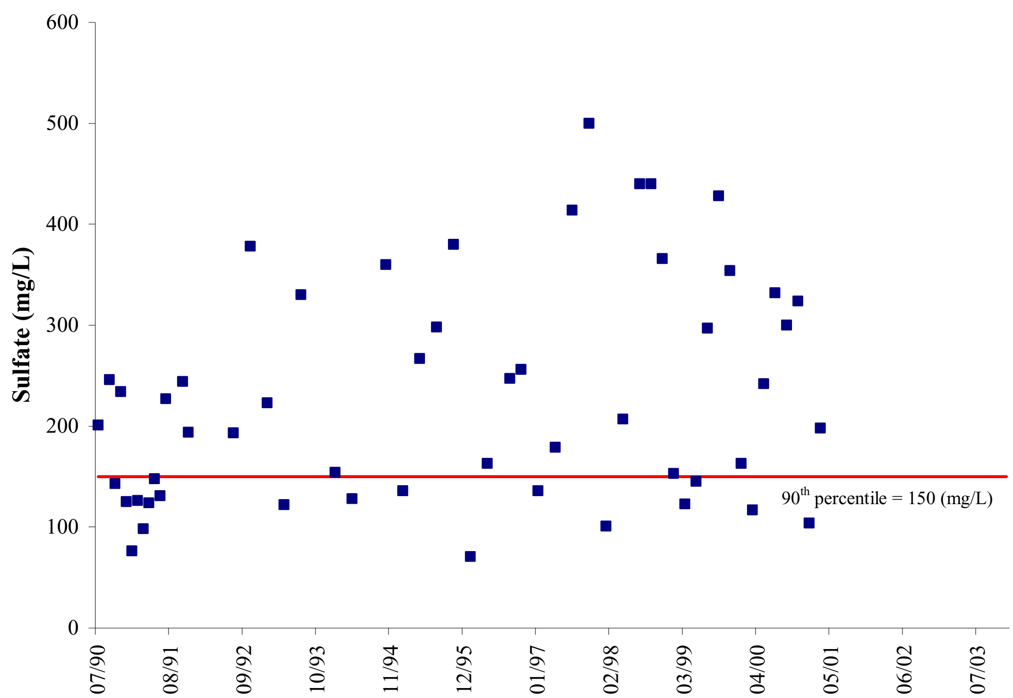

Figure 7.19 SO_4 concentrations at VADEQ station 6BSRA001.11.

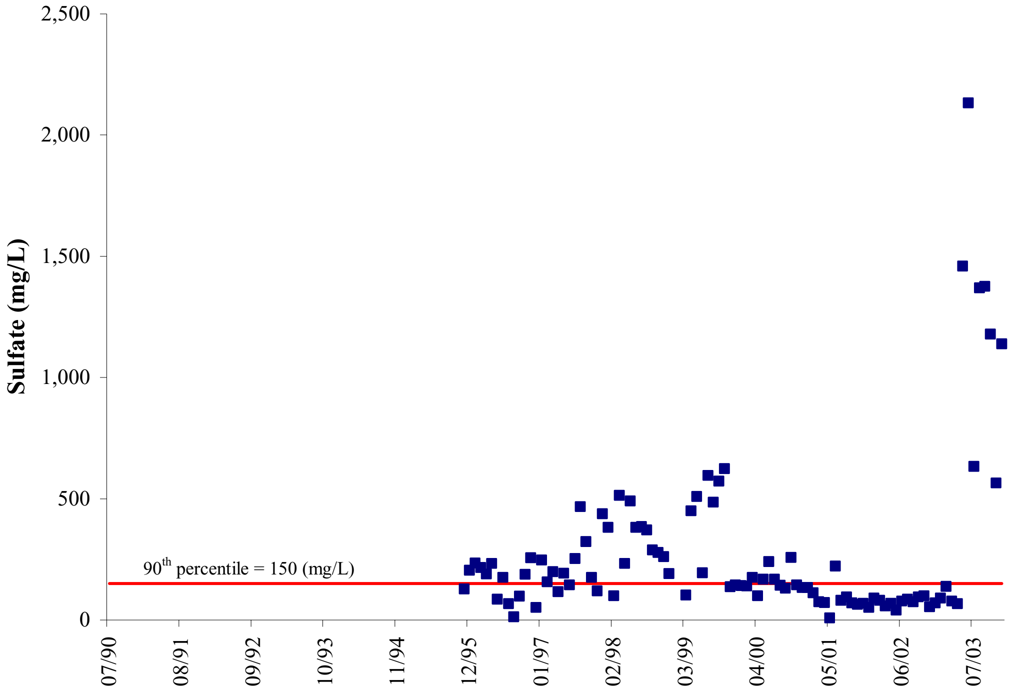

Figure 7.20 SO_4 concentrations at DMME MPID 1020127.

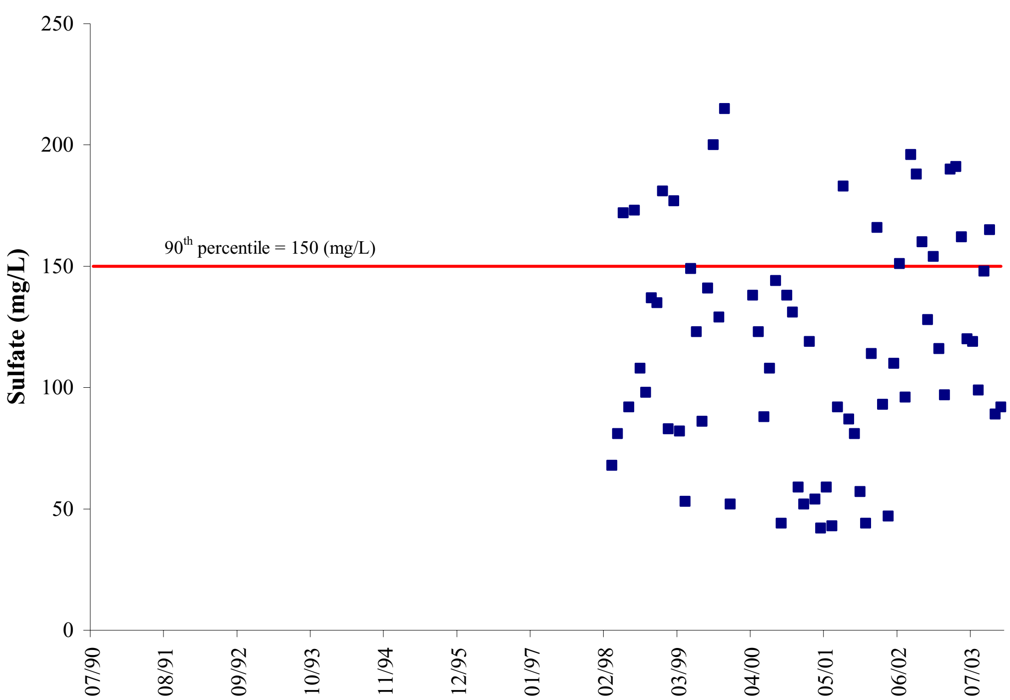

Figure 7.21 SO_4 concentrations at DMME MPID 0002877.

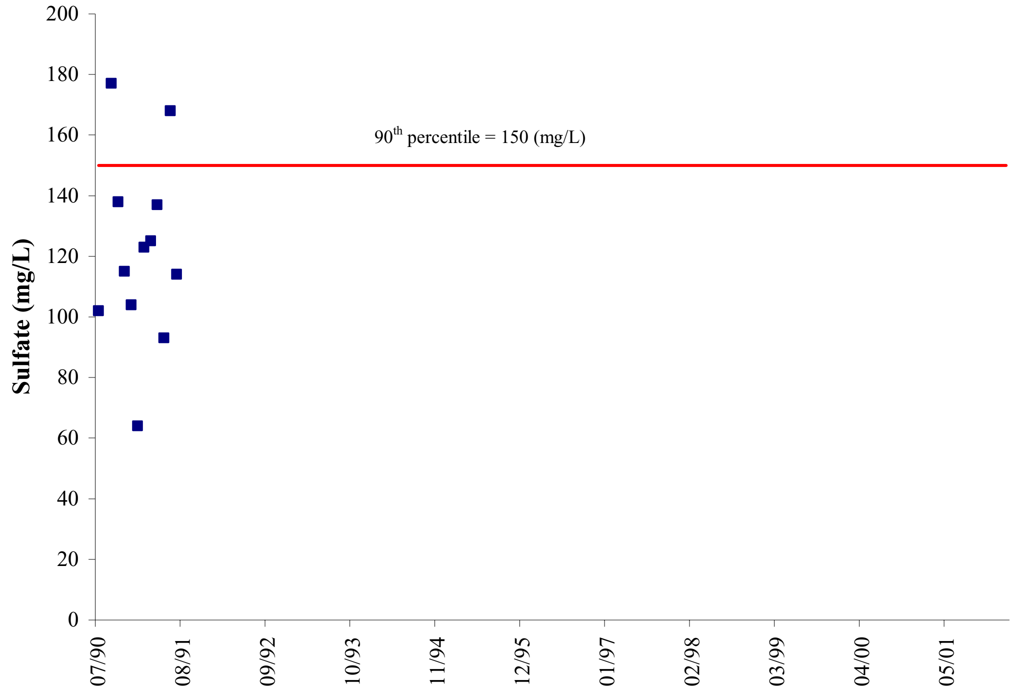

Figure 7.22 SO_4 concentrations at DMME MPID 1020209.

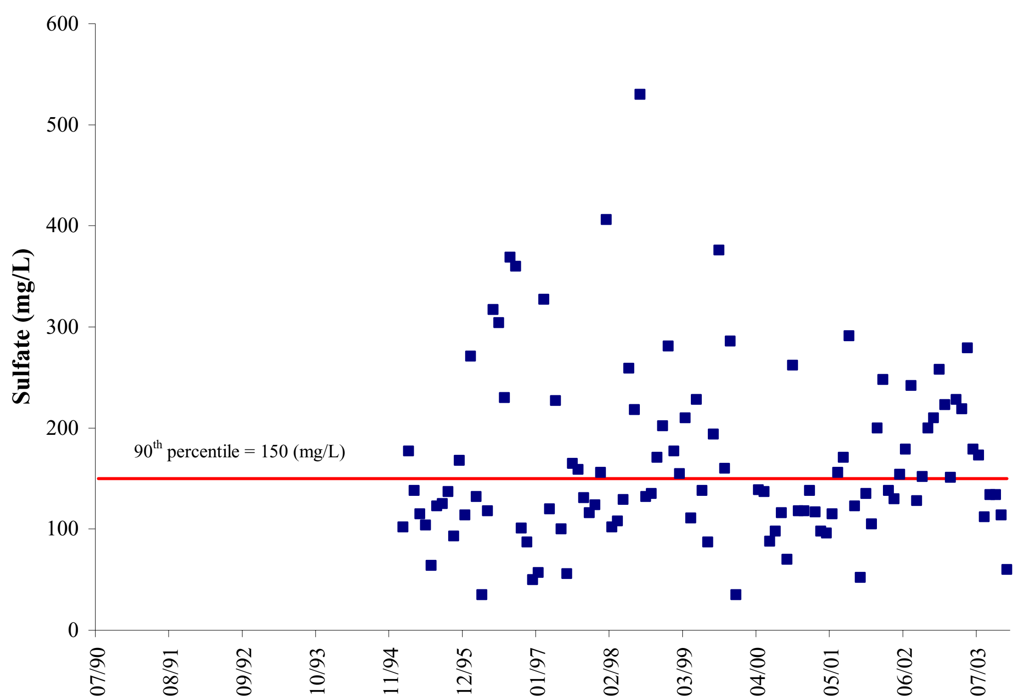

Figure 7.23 SO_4 concentrations at DMME MPID 1020237.

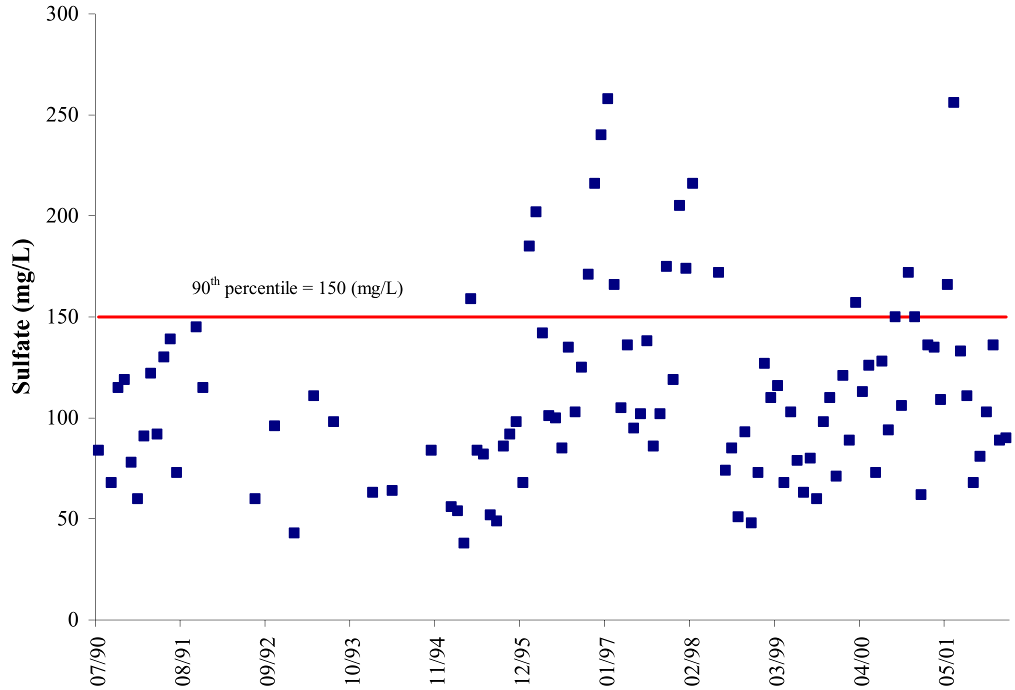

Figure 7.24 SO_4 concentrations at DMME MPID 1020226.

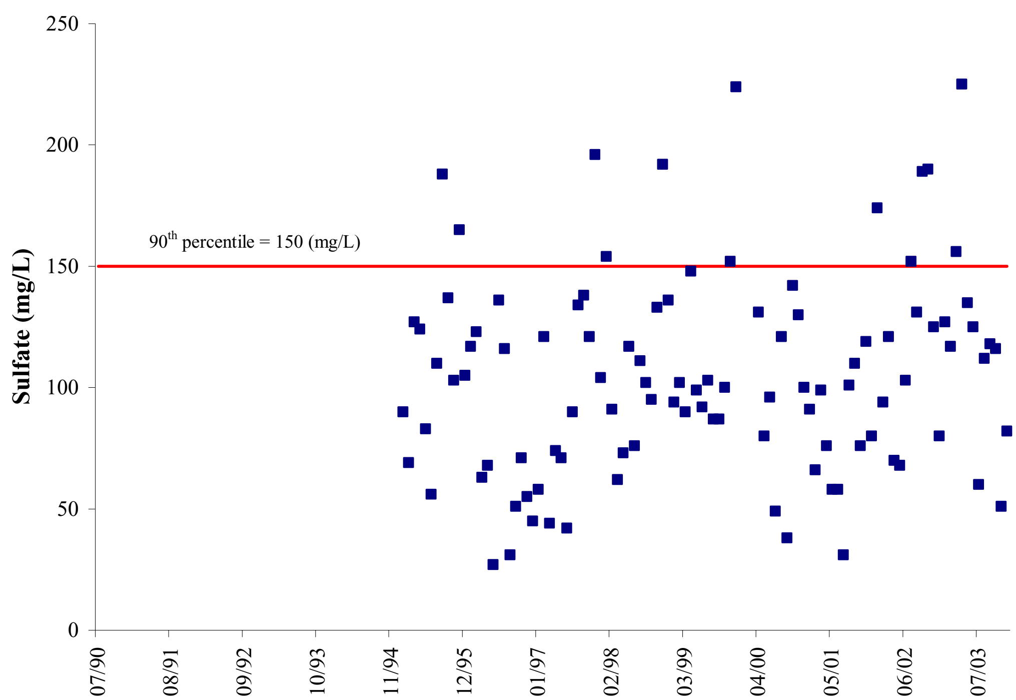

Figure 7.25 SO_4 concentrations at DMME MPID 1020225.

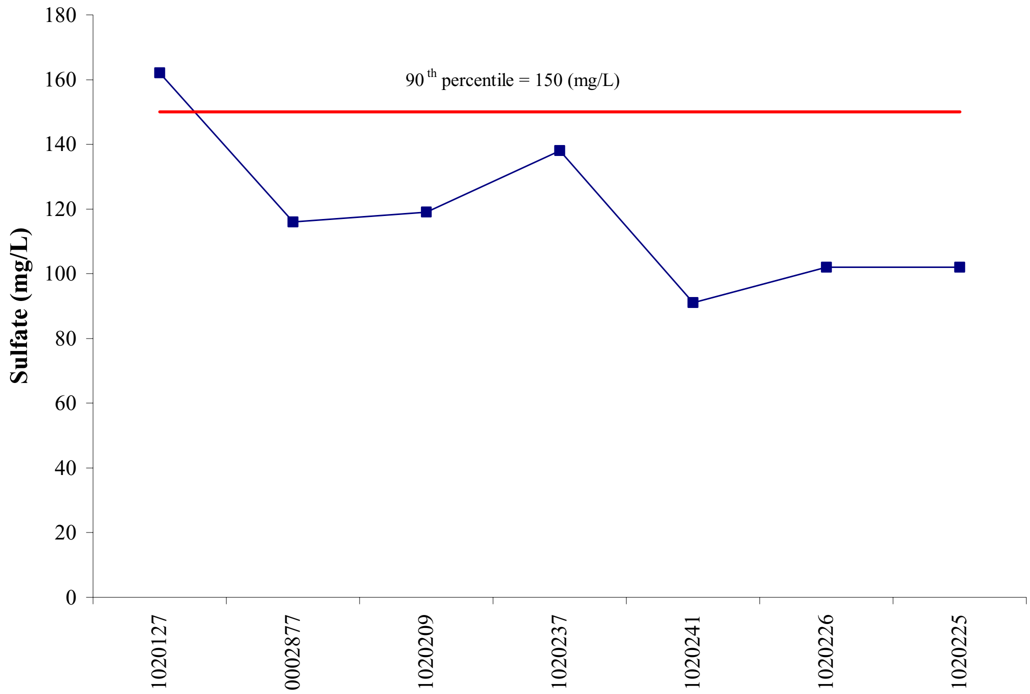

Figure 7.26 Median SO_4 concentrations at DMME MPIDs on Straight Creek.

7.3.3 PH

The maximum and minimum pH values were within the state standard range (6.0≤ pH ≤9.0) at all of the VADEQ stations with one exception at station 6BSRA004.16. The exception was a value of 9.28 (std units) measured in March of 2004. Median pH values were within the state standards range at four VADEQ stations (Figure 7.27). Maximum and minimum pH values were within the state standard range at the seven DMME MPIDs on Straight Creek. Median values are shown in Figure 7.28. In addition, all seven pH measurements collected by ECI on Straight Creek were within the state water quality standards range.

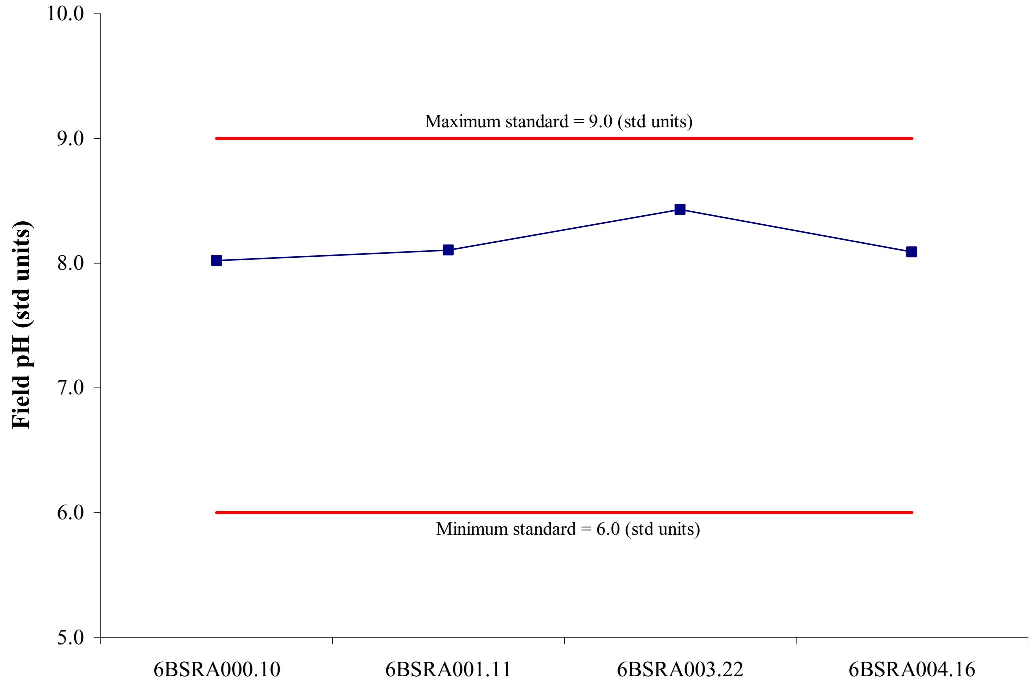

Figure 7.27 Median field pH values at VADEQ stations on Straight Creek.

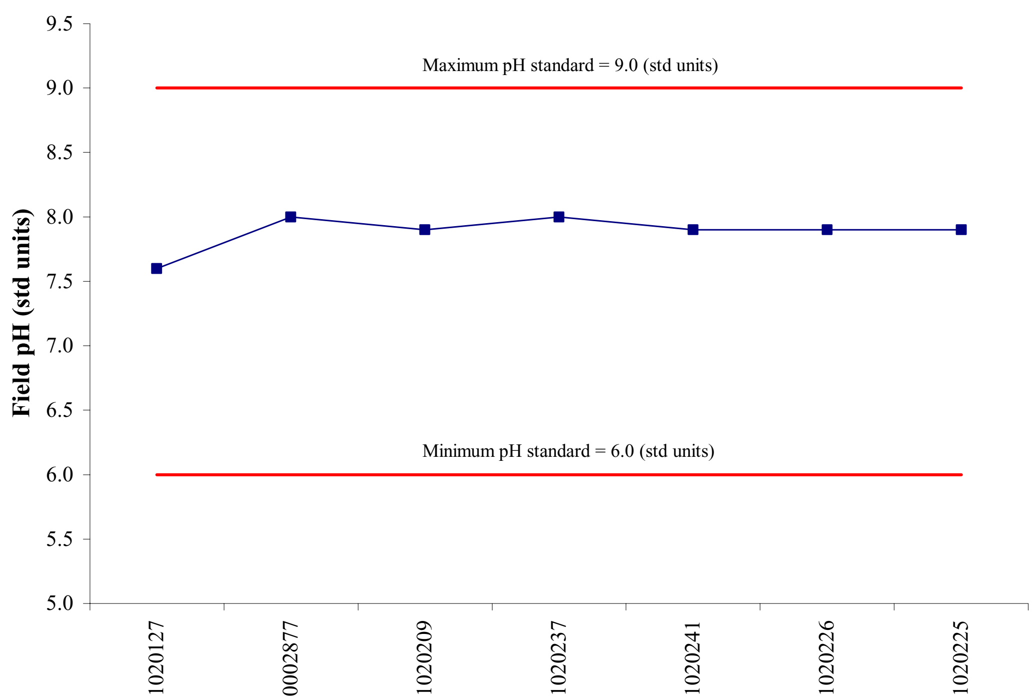

Figure 7.28 Median field pH values at DMME MPIDs on Straight Creek.

Alkalinity concentrations were excessive at three DMME MPIDs based on a 90th percentile value of 200 mg/L calculated from the McClure River (6AMCR000.20) data (Table 7.9 and Figures 7.29 through 7.31). Median alkalinity concentrations at the DMME MPIDs were below the 90th percentile value of 200 mg/L (Figure 7.32). Alkalinity concentrations did not exceed the 90th percentile value at VADEQ station 6BSRA001.11 (Figure 7.33). However, ECI measured an alkalinity concentration of 1,144 mg/L at site SB, which is downstream of the confluence with Fawn Branch (river mile 2.40). Alkalinity is measured in terms of $CaCO_3$ and it is used as a measure of the buffering capacity of a stream. Too little, as well as too much can be harmful to aquatic life; however, there are no water quality standards or screening values for alkalinity. Excessive alkalinity concentrations can contribute to high conductivity and total dissolved solids values, which will be discussed in more detail later in the analysis. Based on the fact that alkalinity concentrations are excessive and there was a pH maximum water quality exceedance, pH is considered a possible stressor.

Table 7.9 DMME MPIDs with excessive alkalinity concentrations.

MPID	River Mile	% Exceedances	Range (mg/L)
0002877	4.87	12	16 – 385
1020209	5.32	17	79 – 333
1020237	5.37	21	14 – 674

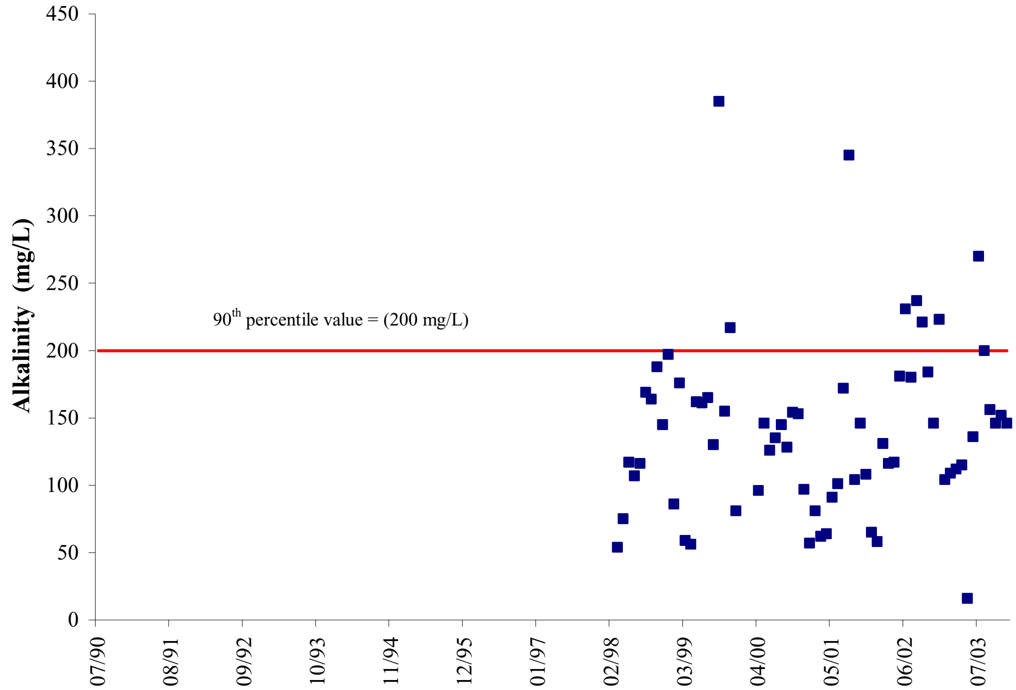

Figure 7.29 Alkalinity concentrations at DMME MPID 0002877.

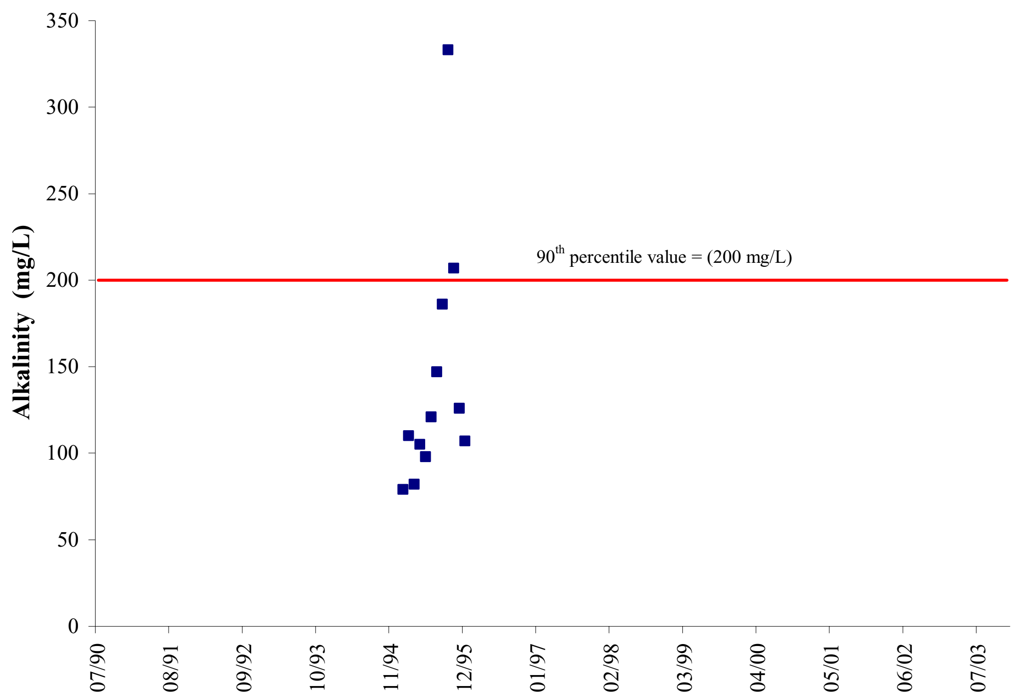

Figure 7.30 Alkalinity concentrations at DMME MPID 1020209.

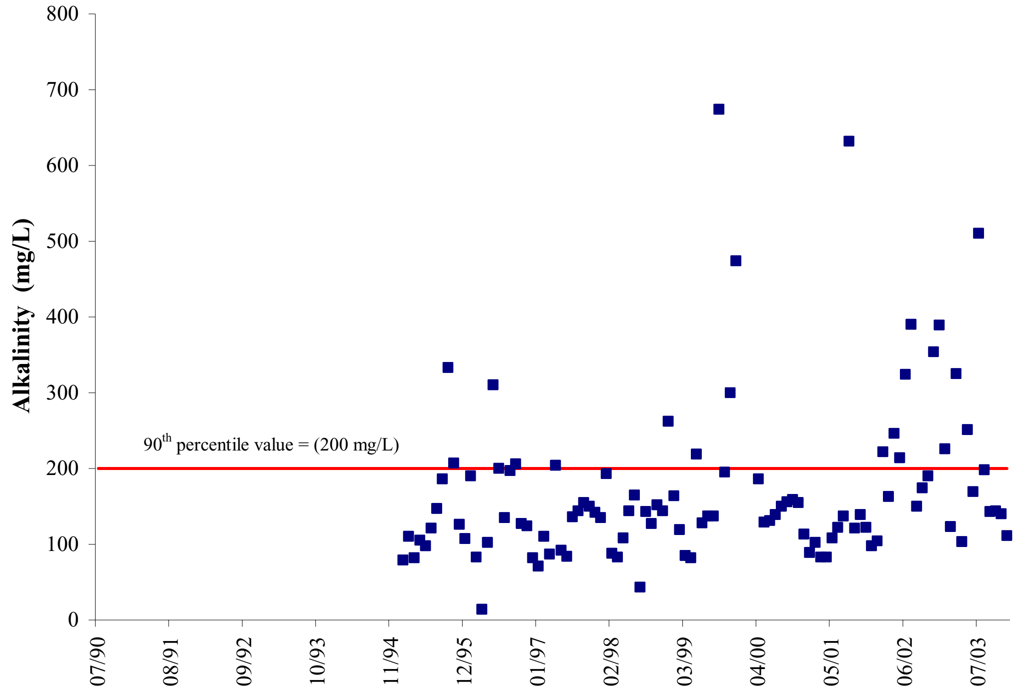

Figure 7.31 Alkalinity concentrations at DMME MPID 1020237.

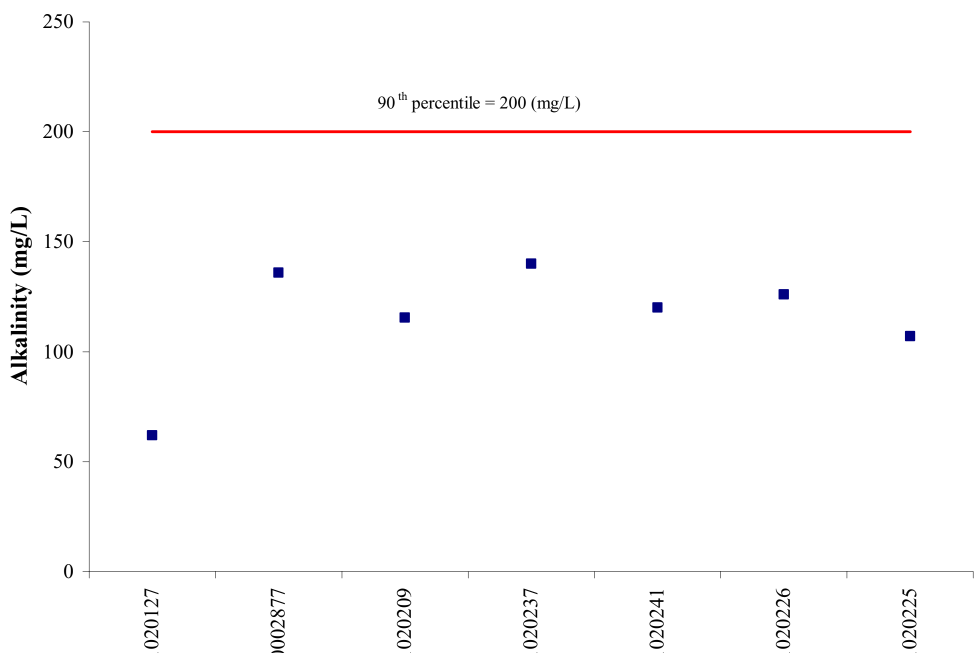

Figure 7.32 Median alkalinity concentrations at DMME MPIDs on Straight Creek.

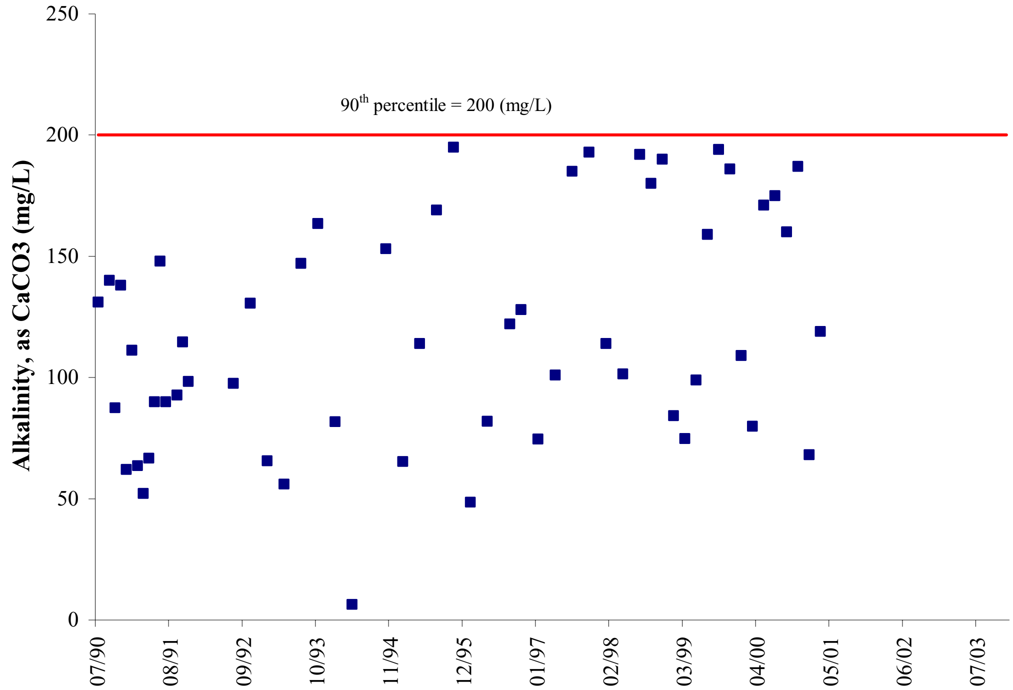

Figure 7.33 Alkalinity concentrations at VADEQ station 6BSRA001.11.

7.3.4 Nickel

Four out of ten sediment samples values were above the PEC value of 48.6 mg/kg for nickel (Ni) at VADEQ station 6BSRA001.11 (Figure 7.34). The maximum value reported was 64.5 mg/kg and the median was 43 mg/kg. In the absence of sediment toxicity data confirming whether nickel is bioavailable or not, it is considered a possible stressor.

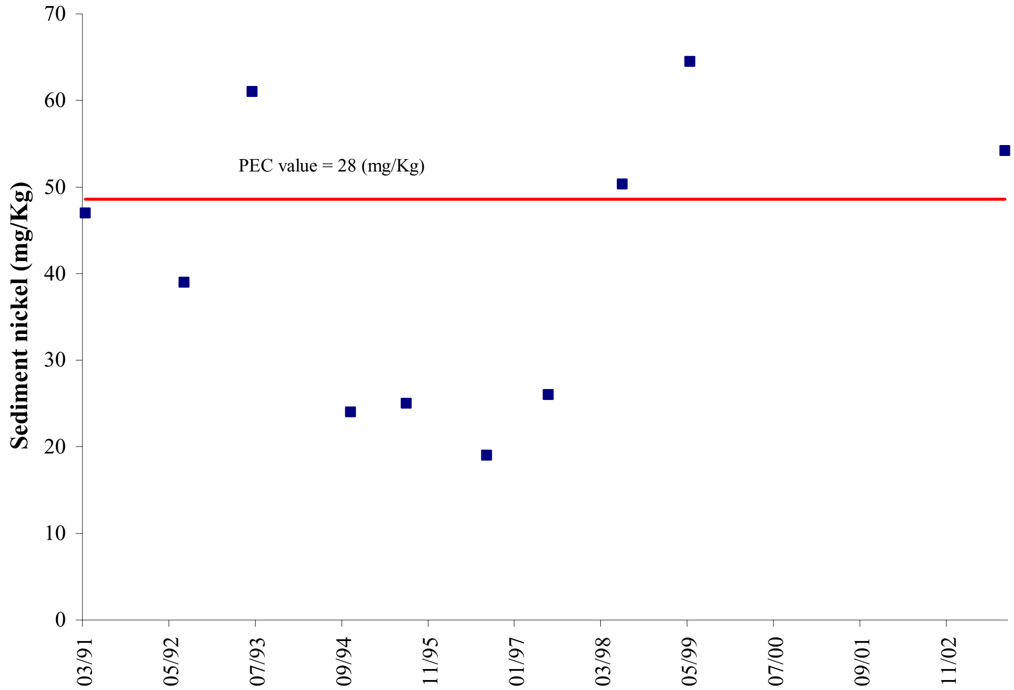

Figure 7.34 Ni sediment values at VADEQ station 6BSRA001.11.

7.3.5 Organic matter

Several different parameters were used to determine if organic matter in the stream was impacting the benthic macroinvertebrate community. Biochemical oxygen demand (BOD_5) provides an indication of how much dissolved organic matter is present. Total organic carbon (TOC), chemical oxygen demand (COD), and volatile suspended solids (VSS) provide an indication of particulate organic matter in a stream, and volatile solids (VS) measure how much dissolved organic matter is present. There is no water quality standard or screening value for BOD_5, therefore a 90th percentile value of 2.0 mg/L was calculated from the McClure River data (6AMCR000.20). This value was not exceeded in more than 10% of the concentrations at VADEQ station 6BSRA001.11.

COD concentrations are considered excessive because 24% of the concentrations at VADEQ station 6BSRA001.11 exceeded the 90th percentile value of 12.5 mg/L (Figure 7.35). TOC concentrations, on the other hand, were very low. VS concentrations are excessive, with 13% surpassing the 90th percentile value of 68 mg/L (Figure 7.36). VSS are excessive with 41% exceeding the 90th percentile value of 3.4 mg/L (Figure 7.37).

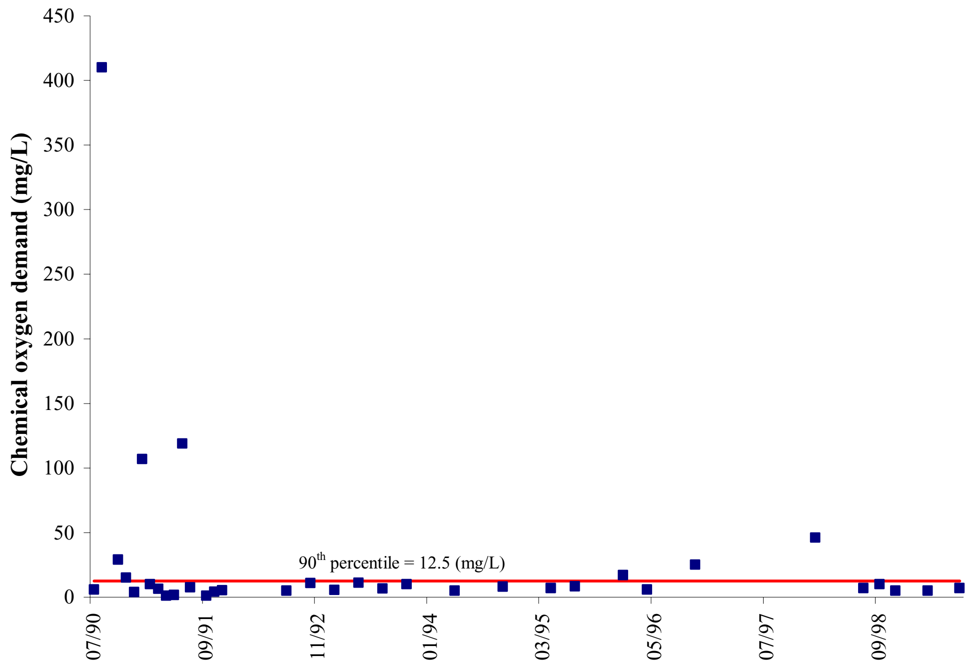

Figure 7.35 COD concentrations at VADEQ station 6BSRA001.11.

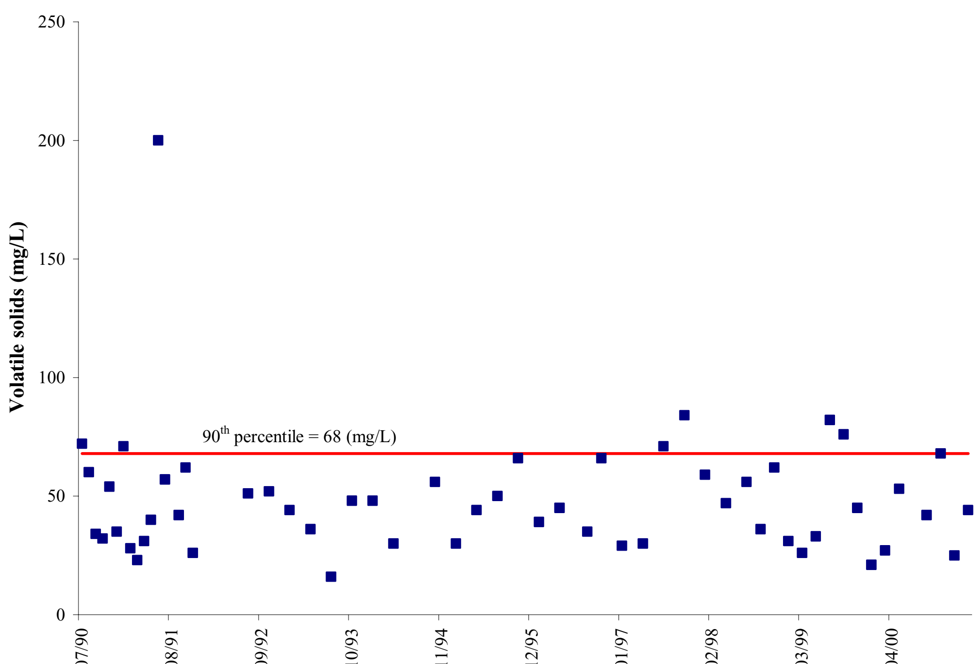

Figure 7.36 VS concentrations at VADEQ station 6BSRA001.11.

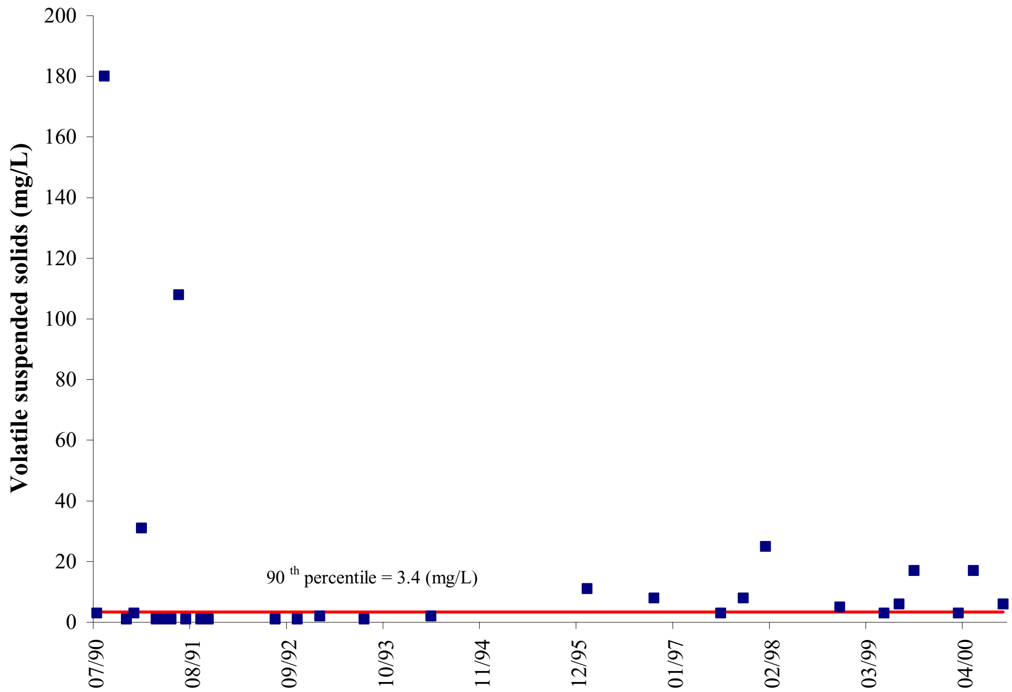

Figure 7.37 VSS concentrations at VADEQ station 6BSRA001.11.

The benthic metrics also indicate that organic matter is a potential problem in Straight Creek; the benthic metric MFBI can be an indicator of excessive organic solids. The average MFBI score was greater in Straight Creek relative to the reference stations. MFBI scores range from 0 to 10 and increasing values have been correlated with increasing organic matter. MFBI values alone do not definitively indicate that a benthic population is influenced by organic enrichment. This index provides an indication of the relative pollution tolerance of organisms in the sample. Other stressors can play a role in increasing MFBI values. The average MFBI score for the six benthic surveys at 6BSRA000.40 was 5.74. The reference stations had an average MFBI score of 3.81. The assemblage for benthic station 6BSRA000.40 from the VADEQ Ecological Data Application System (EDAS) database was examined, and hydropsychidae (netspinning caddisflies) were found to be the dominant family (38%). Hydropsychidae represented 10% of the total assemblages at the reference stations. According to Voshell (2002), "If common netspinners account for the majority of the community that is a reliable indicator of organic or nutrient pollution." However, the EPA noted, in a preliminary review of this chapter, that hydropsychidae can thrive in watersheds with mining operations without excessive organic matter levels. Many species of hydropsychidae are tolerant to both metals and high conductivity (Pond, 2005). The dominance of hydropsychidae is reasonable in this watershed. In addition, organic matter increases the productivity of a stream, which normally increases the abundance of benthic macroinvertebrates. Recent benthic monitoring in Straight Creek shows abundance numbers that average less 300 organisms per two square meter sample. Typically in organic enriched streams abundance numbers are expected to be near 1,000 organisms or more. It is anticipated that there will be significant reductions in the primary sources of organic matter via implementation of the fecal bacteria TMDL also being developed for Straight Creek. Therefore, organic matter is considered a possible stressor.

7.4 Probable Stressors

Table 7.10 Probable Stressors in Straight Creek.

Parameter	Location in Document
Conductivity/Total dissolved solids	Section 7.4.1
Sediment	Section 7.4.2

7.4.1 Conductivity/Total dissolved solids

High conductivity values have been linked to poor benthic health (Merricks, 2003) and elevated conductivity is common with land disturbance and mine drainages. In the development of both the Virginia and West Virginia Stream Condition Index, the reference streams used had conductivity levels that did not exceed 500 μmhos/cm. In the absence of a water quality standard or screening value, a 90th percentile value of 800 μmhos/cm was calculated from the McClure River (6AMCR000.20). Conductivity values at the VADEQ stations 6BSRA001.11 and 6BSRA003.22 exceeded the 90th percentile value in 39% and 89% of the samples, respectively (Table 7.11 and Figures 7.38 and 7.39). Median conductivity values exceeded the 90th percentile value of 800 μmhos/cm at VADEQ station 6BSRA003.22 (Figure 7.40). In data provided by DMME, the 90th percentile value was exceeded in 10% of the samples at two DMME MPIDs (Table 7.11 and Figures 7.41 and 7.42). Median conductivity values for all seven DMME MPIDs are shown in Figure 7.43.

The state of Mississippi has a water quality conductivity standard of 1,000 µmhos/cm (MDEQ, 2004). The VADEQ stations and DMME MPIDs had a total of 57 conductivity measurements that exceeded 1,000 µmhos/cm. The conductivity measurements exceeded 1,000 µmhos/cm in 24%, 89%, 20% and 14% of the samples taken at 6BSRA001.11, 6BSRA003.22, MPID 1020127, and 1020237, respectively.

Table 7.11 VADEQ stations and DMME MPIDs with excessive conductivity values.

MPID or VADEQ Station	River Mile	% Exceedances	Range (µmhos/cm)
6BSRA001.11	1.11	39.4	40.1 – 2,114
6BSRA003.22	3.22	88.9	581.5 – 2,251
1020127	3.26	25.0	130 – 5,800
1020237	5.37	39.4	270 – 2,620

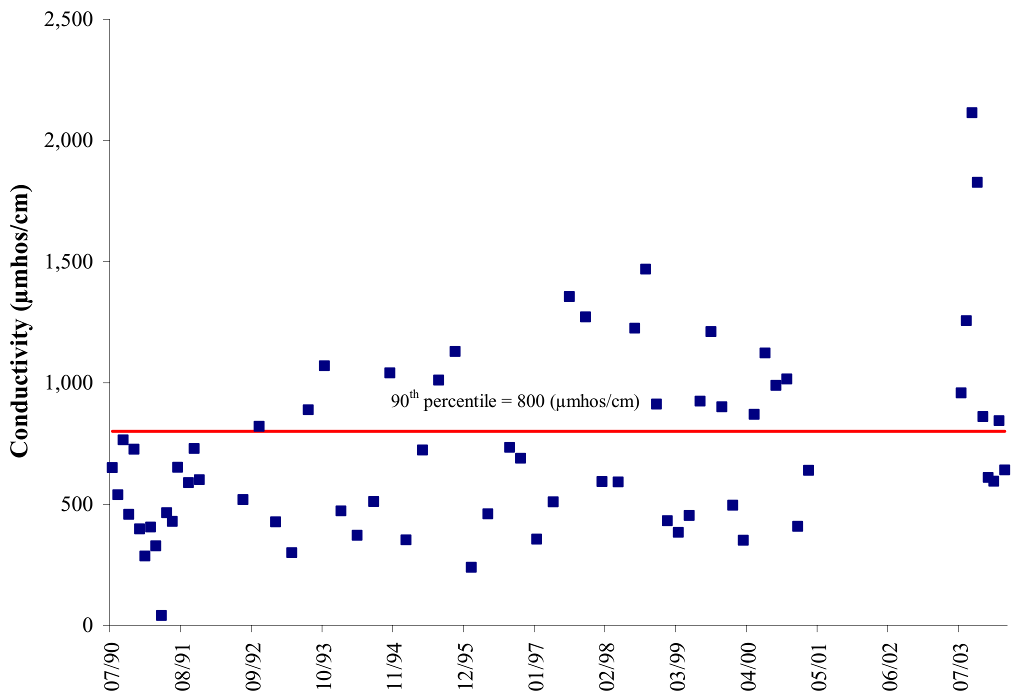

Figure 7.38 Conductivity measurements at VADEQ station 6BSRA001.11.

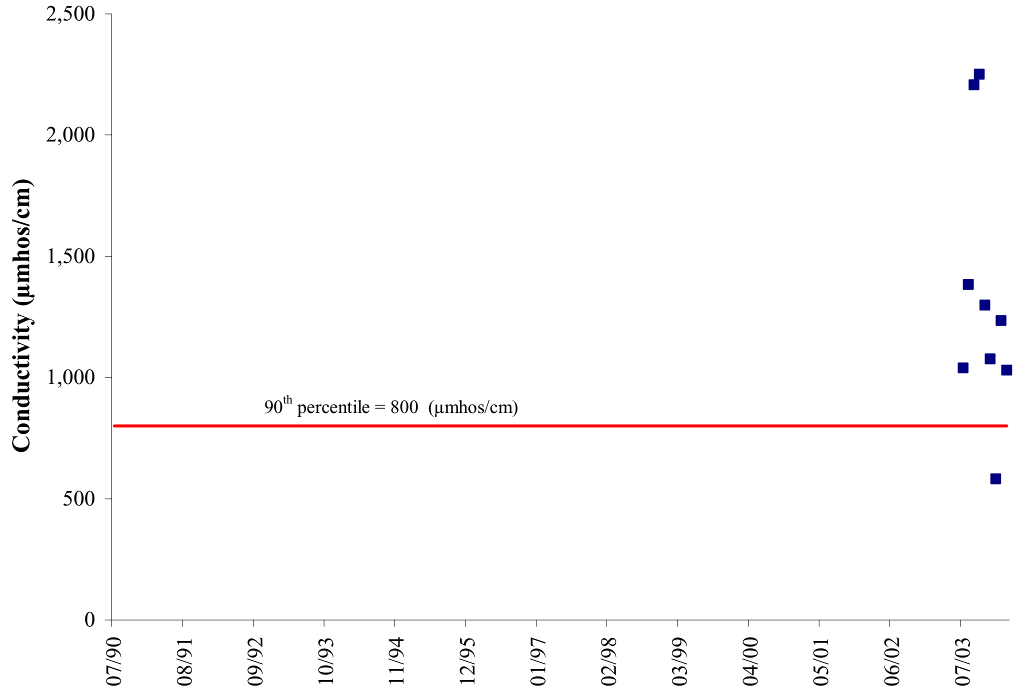

Figure 7.39 Conductivity measurements at VADEQ station 6BSRA003.22.

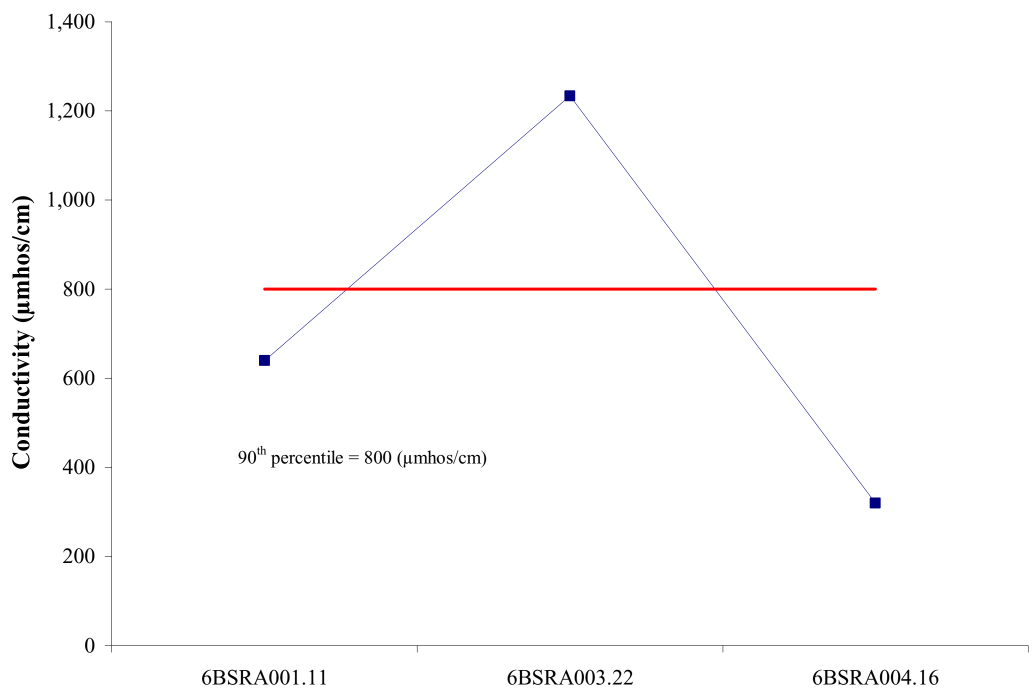

Figure 7.40 Median conductivity values at VADEQ stations on Straight Creek.

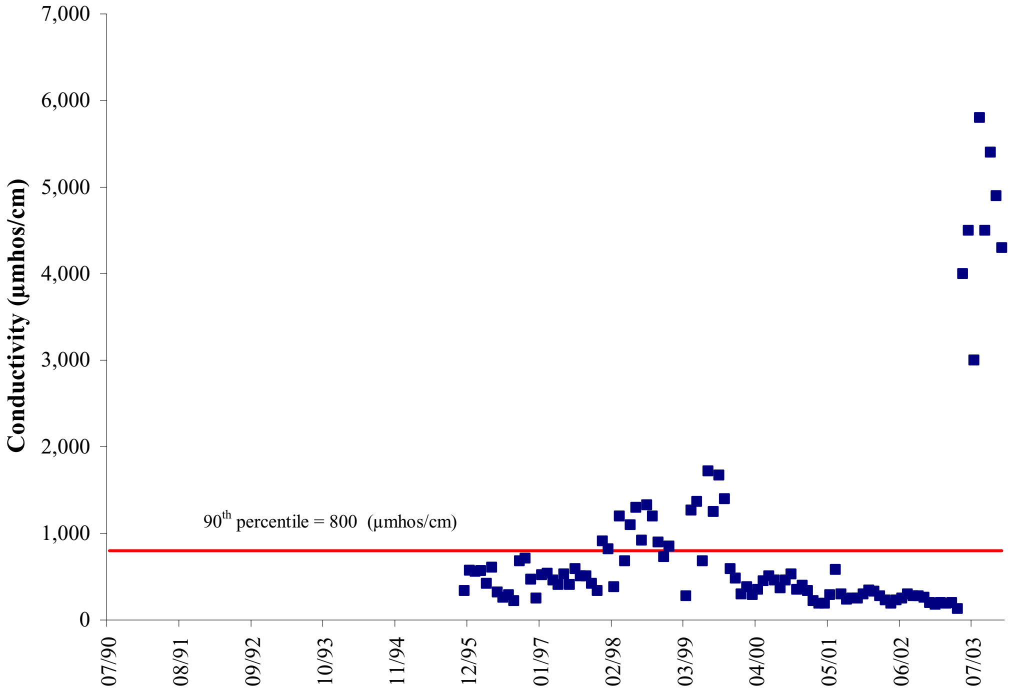

Figure 7.41 Conductivity measurements at DMME MPID 1020127.

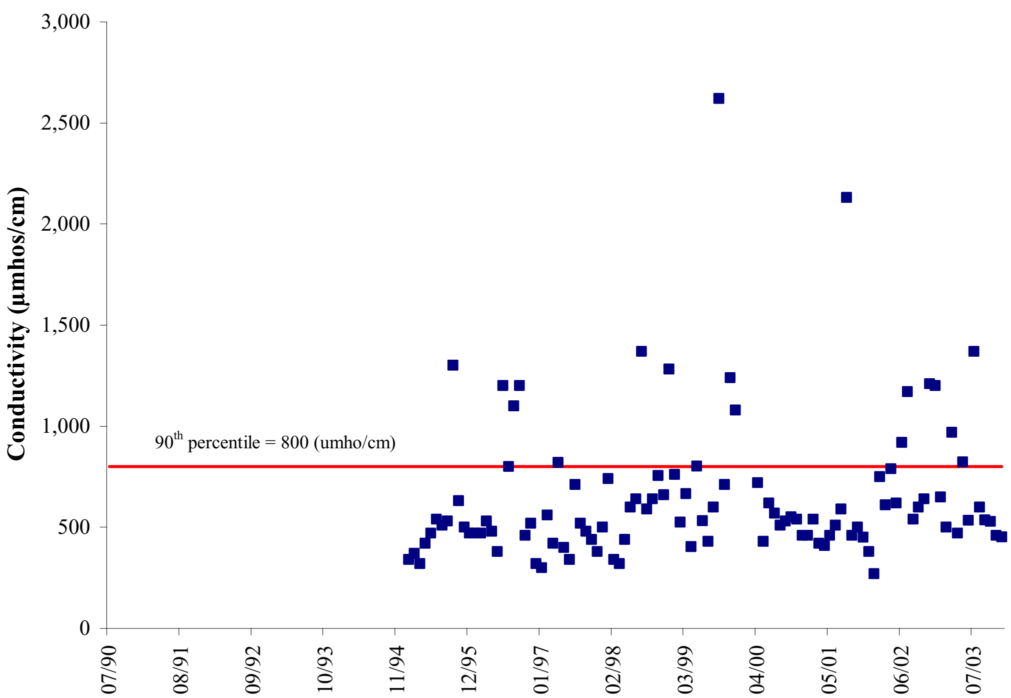

Figure 7.42 Conductivity measurements at DMME MPID 1020237.

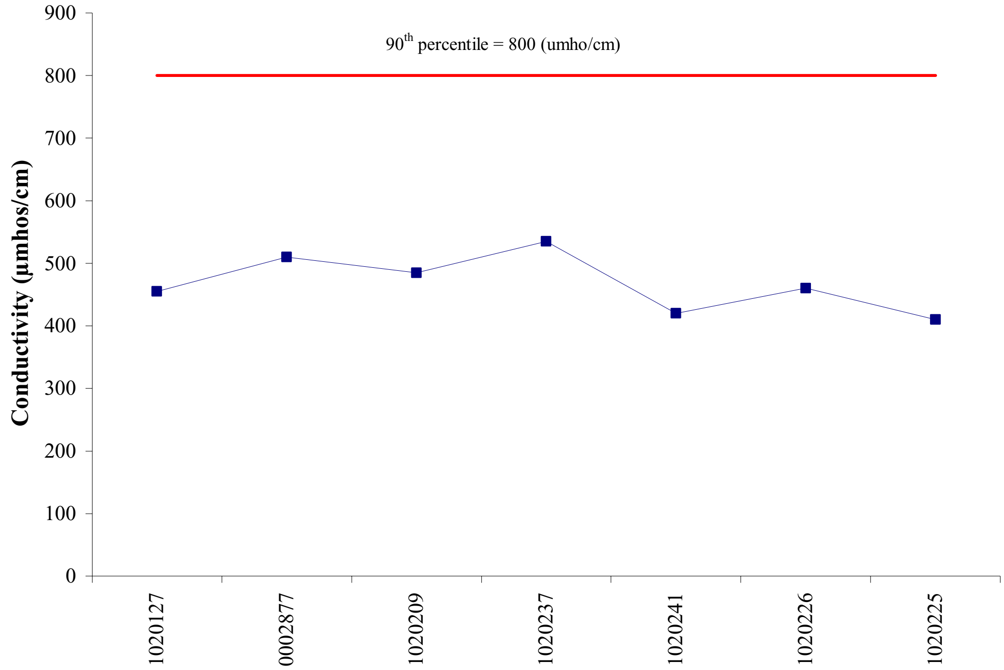

Figure 7.43 Median conductivity measurements at DMME MPIDs on Straight Creek.

Conductivity is a measure of the electrical potential in the water based on the ionic charges of the dissolved compounds that are present. TDS is a measure of the actual concentration of the dissolved ions, dissolved metals, minerals, and organic matter in water. Dissolved ions can include sulfate, calcium carbonate, chloride, etc. Therefore, even though they are two different measurements, there is a direct correlation between conductivity and TDS.

A TDS 90th percentile value of 525 mg/L was calculated from the McClure River (6AMCR000.20) data. TDS concentrations were excessive at VADEQ stations 6BSRA001.11 and 6BSRA003.22 (Table 7.12 and Figures 7.44 and 7.45) and at DMME MPIDs 1020127 and 1020237 (Table 7.12 and Figures 7.46 and 7.47). Median TDS values exceeded the 90th percentile value of 525 mg/L at VADEQ station 6BSRA003.22 (Figure 7.48). Median values for all of the DMME MPIDs are shown in Figure 7.49. TDS toxicity depends on the relative contribution of the various ions it includes. Therefore, toxicity cannot only vary between different watersheds but within the same watershed.

Ohio and Illinois have aquatic life TDS water quality standards set at 1,500 mg/L (OEPA, 2005; IPCB, 2005). The VADEQ stations and DMME MPIDs had a total of 14 TDS concentrations that exceeded 1,500 mg/L. The TDS concentrations at MPID 1020127 (river mile 3.26) exceeded 1,500 mg/L 11 times; eight of these were between May and December 2003. In addition, New Jersey and Kentucky all have aquatic life water quality standards addressing TDS (NJ Dept. of Environmental Protection, 2005; Kentucky Administrative Regulations Title 401, 2005). The fact that five states consider high TDS and conductivity a problem and have implemented state standards, shows there is concern over the affect these constituents have on aquatic life.

Table 7.12 VADEQ stations and DMME MPIDs with excessive TDS values.

MPID or VADEQ Station	River Mile	% Exceedances	Range (mg/L)
6BSRA001.11	1.11	40.0	179 - 1,320
6BSRA003.22	3.22	77.8	450 - 1,560
1020127	3.26	29.2	30 - 5,122
1020237	5.37	26.7	35 – 1,596

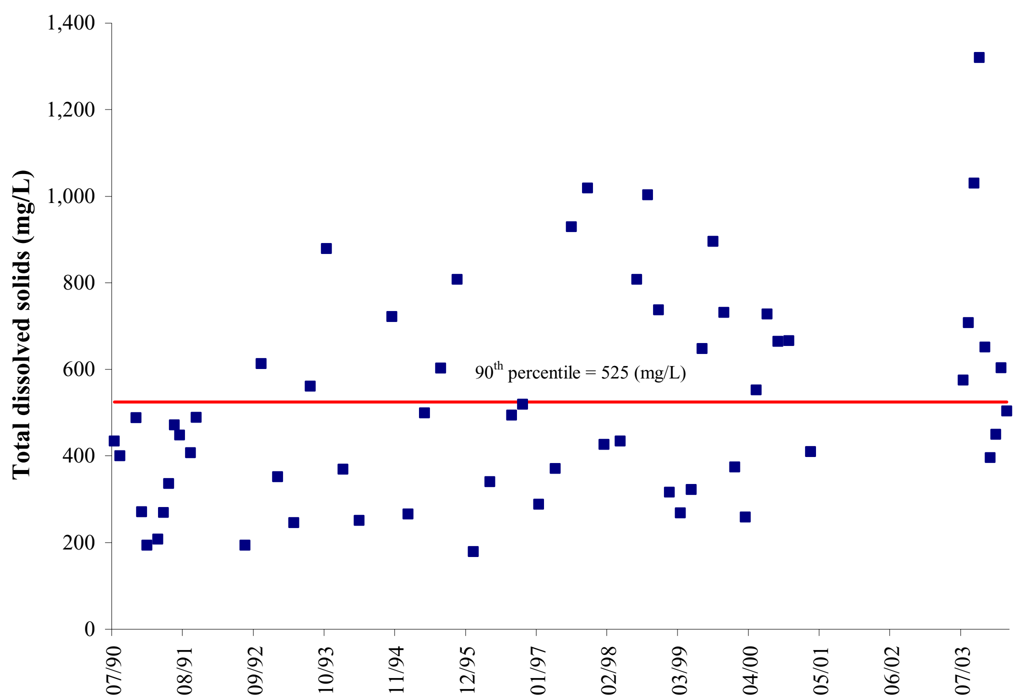

Figure 7.44 TDS concentrations at VADEQ station 6BSRA001.11.

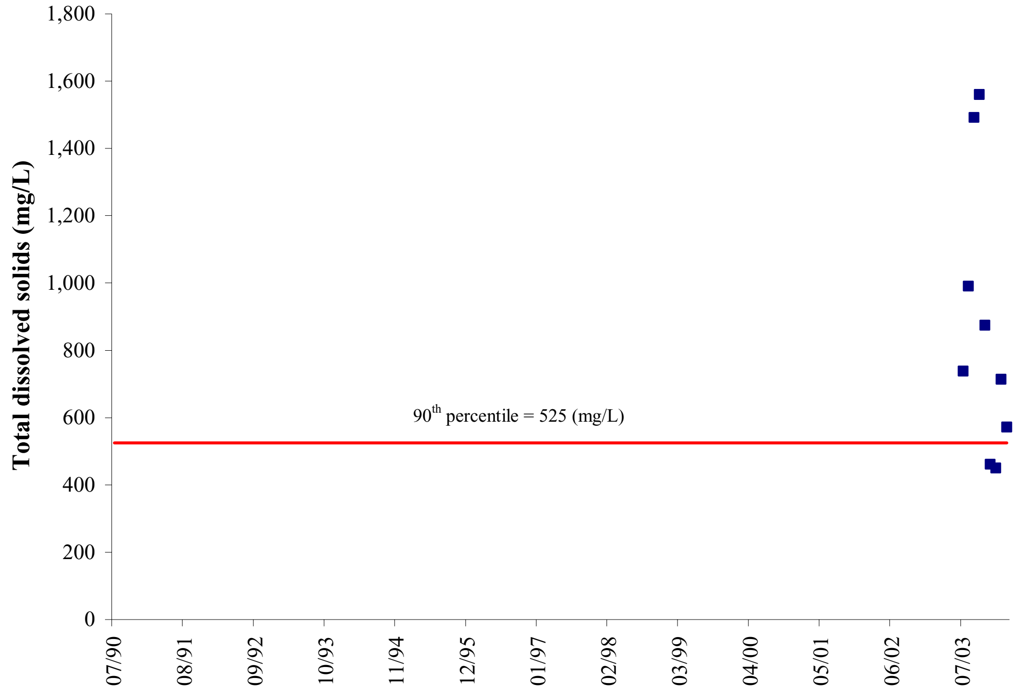

Figure 7.45 TDS concentrations at VADEQ station 6BSRA003.22.

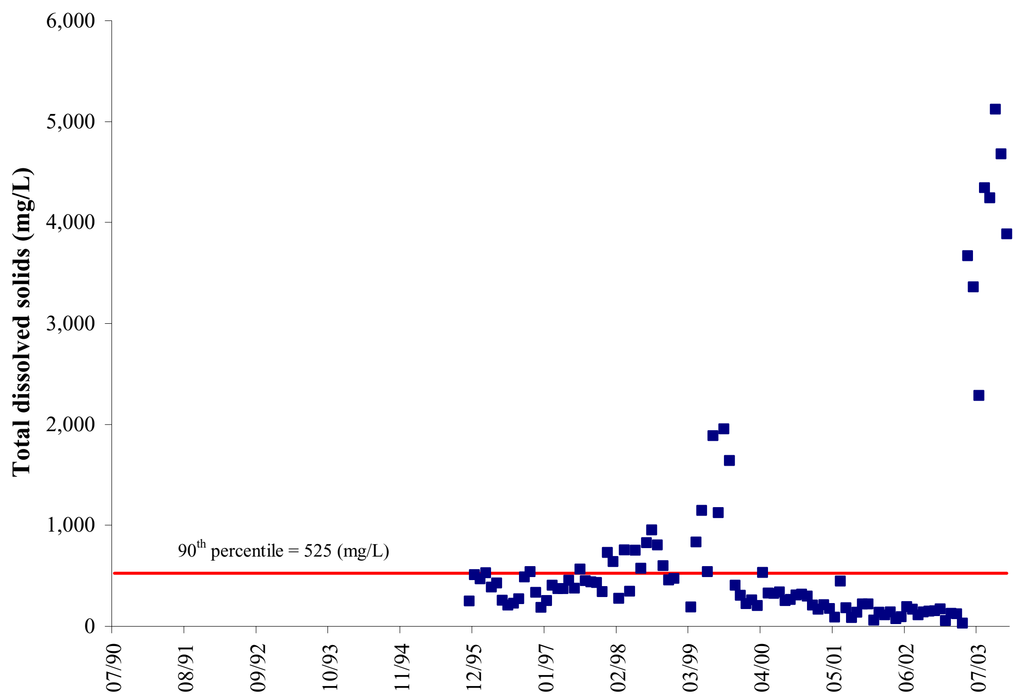

Figure 7.46 TDS concentrations at DMME MPID 1020127.

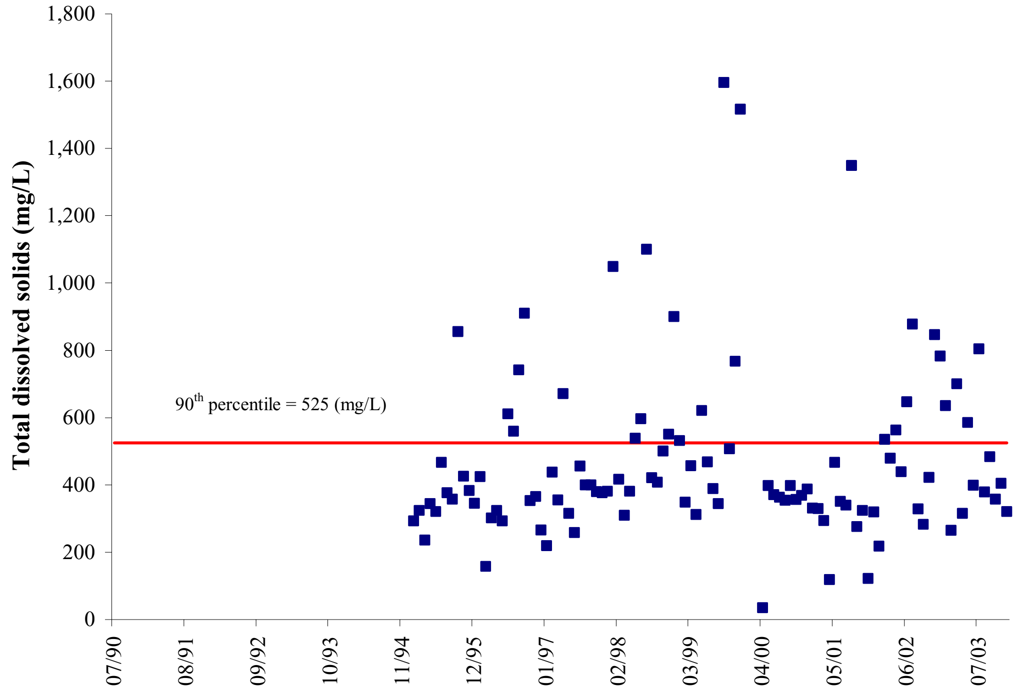

Figure 7.47 TDS concentrations at DMME MPID 1020237.

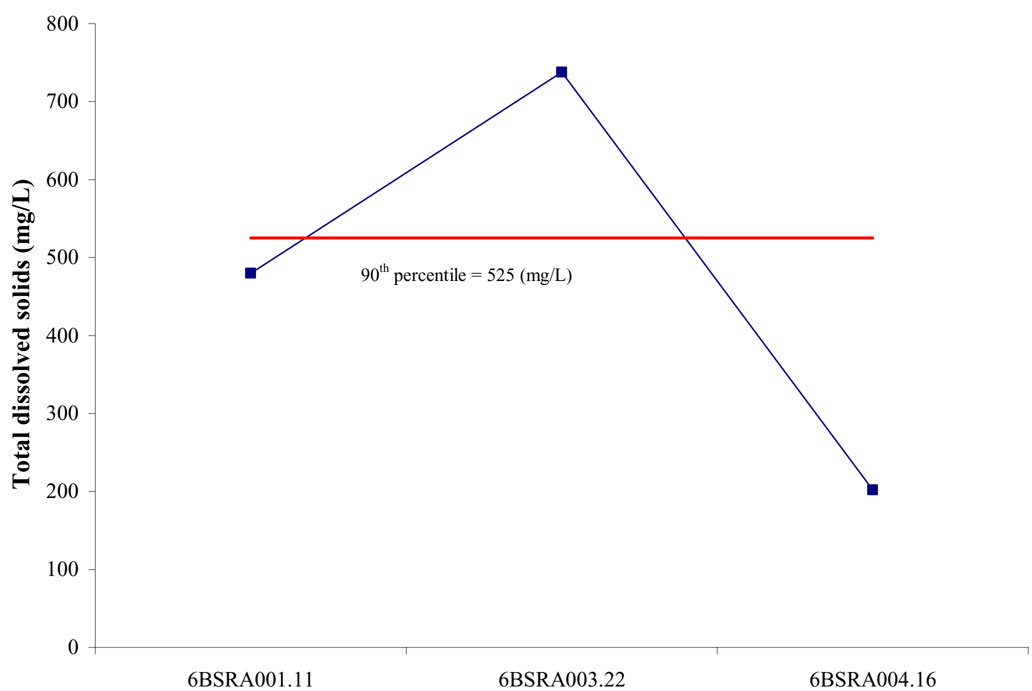

Figure 7.48 Median TDS concentrations at VADEQ stations on Straight Creek.

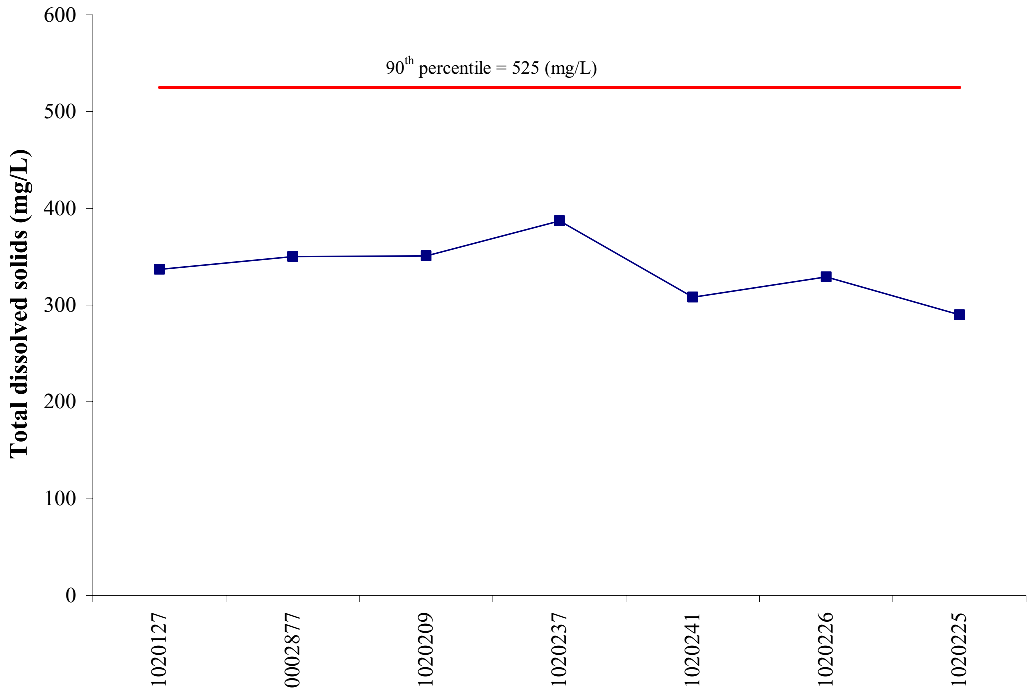

Figure 7.49 Median TDS concentrations at DMME MPIDs on Straight Creek.

TDS concentrations can be harmful to aquatic organisms without causing death. Aquatic organisms balance water and internal ions through a number of different mechanisms. Therefore high concentrations and significant changes in TDS over long periods of time can place a lot of stress on the organisms. The resulting chronic stress affects processes such as growth and reproduction. Sudden large spikes in TDS concentration can be fatal. In general, if TDS concentrations in freshwater effluents (discharges from industrial or municipal wastewater treatment facilities) is above 1,340 mg/L, the concentration of dissolved ions can be high enough to stress aquatic organisms (Society of Environmental Toxicology and Chemistry, 2004). A similar research paper noted that conductivity can be used as a screening tool for TDS toxicity in freshwater effluents. In general, if the conductivity of a freshwater effluent exceeds 2,000 µmhos/cm then the concentration of dissolved ions can be high enough to cause stress to aquatic organism (Goodfellow et al., 2000). Conductivity values exceeded 2,000 µmhos/cm at both VADMME and VADEQ monitoring stations on Straight Creek.

A study of TDS toxicity in a coal mining watershed in southeastern Ohio found the lowest observed effect concentration (LOEC) on the test organism *Isonychia bicolor* (a species of Mayfly) was 1,066 mg/L (Kennedy, 2002). The author carefully noted that this concentration was specific to the watershed studied, but noted that similar studies with the same test organism and TDS with varying ionic compositions were toxic between 1,018 and 1,783 mg/L (Kennedy, 2002). Kennedy referenced a study that suggested aquatic organisms should be able to tolerate TDS concentrations up to 1,000 mg/L; however, the test organism used was *Chironomous tentans*, which is considerably more pollution tolerant than *Isonychia bicolor* (Kennedy, 2002).. Research also indicates that the likely mechanism(s) of TDS benthic macroinvertebrate mortality is from gill and internal tissue dehydration, salt accumulation and compromised osmoregulatory function. In fact, the rate of change in TDS concentrations may be more toxic to benthic macroinvertebrates than the TDS alone (Kennedy, 2002).

A recent report on the effects of surface mining on headwater stream biotic integrity in Eastern Kentucky noted that one of the most significant stressors in these watersheds was elevated TDS (Pond, 2004). Elevated TDS concentrations impact pollution sensitive mayflies the most. Figure 7.50 from this report shows that "drastic reductions in mayflies occurred at sites with conductivities generally above 500 µmhos/cm" (approximately 375 mg/L TDS) (Pond, 2004).

Pond speculated that the increased salinity may irritate the gill structures on mayflies and inhibit the absorption of oxygen but research has not confirmed this. He also noted that mayfly sensitivity to increases in dissolved ions varies by genus. For example, the genera *Baetis, Isonychia* and *Caenis* commonly inhabit streams with elevated conductivity (Pond, 2004). The benthic monitoring results from VADEQ and ECI sampling showed that mayflies made up only 15% and 16% of the total benthic assemblage, respectively. A typical reference station in this part of the state can be expected to have at least nearly 50% mayflies out of the total assemblage. These surveys only produced family level data but it is significant that in the VADEQ and ECI data the families Baetidae, Isonychiidae and Caenidae comprised 83 and 87% of the total mayflies, respectively.

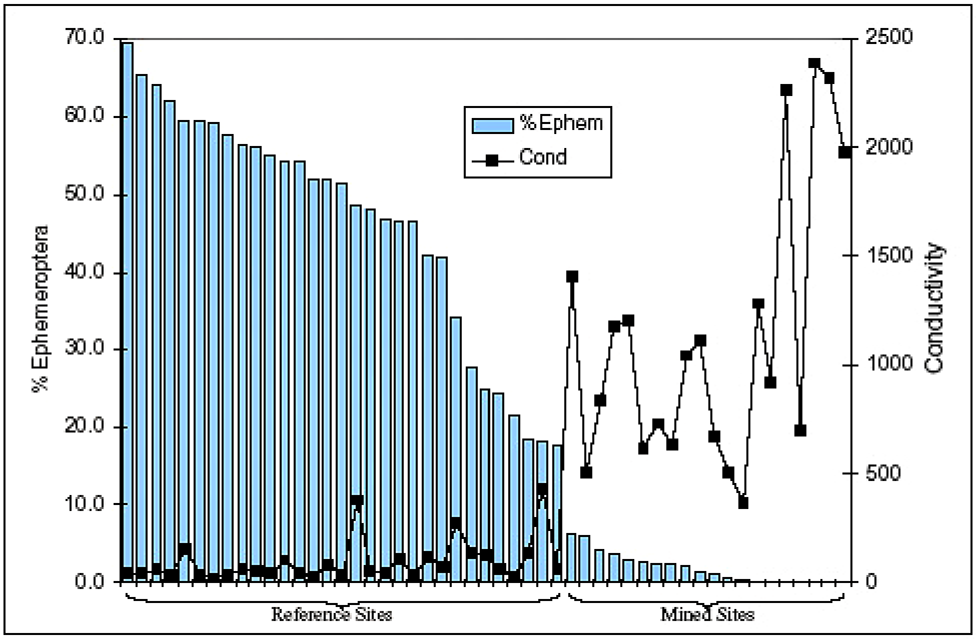

Figure 7.50 The relationship between %Ephemeroptera and conductivity from reference and mined sites (Pond, 2004).

It is clear from the data available that conductivity and TDS values are too high and there have been very large fluctuations over the sampling period. There seems to be little doubt that the extremely high TDS concentrations often present in Straight Creek are responsible for depressing the sensitive benthic community. Therefore, conductivity and TDS are considered probable stressors. Modeling and subsequent allocations will focus on TDS.

7.4.2 Sediment

The median habitat scores were marginal for metrics that indicate sediment problems. Embeddedness scores were low in a majority of the benthic monitoring done prior to 2002 and sediment deposition scores were marginal at various monitoring stations on Straight Creek throughout the sampling period. Marginal sediment deposition scores indicate large-scale movements of sediment in the stream. Bank stability, bank vegetation and riparian vegetation scored in the marginal category at various VADEQ monitoring stations on Straight Creek throughout the sampling period. Marginal scores for these habitat metrics are indicative of potential erosion during high flows and the subsequent deposition of more sediment. Total suspended solids (TSS) concentrations exceeded the 90th percentile of 25 mg/L at six of the seven DMME MPIDs (Table 7.13 and Figures 7.51 - 7.55). Median TSS concentrations for the DMME MPID sites are shown in Figure 7.56. TSS concentrations also exceeded the 90th percentile in 23% of samples collected from the VADEQ station 6BSRA001.11 (Figure 7.57).

Table 7.13 VADEQ stations and DMME MPIDs with excessive TSS values.

MPID or VADEQ Station	River Mile	% Exceedances	Range (mg/L)
6BSRA001.11	1.11	23	0.8 - 1,460
1020127	3.26	12	2 – 112
1020209	5.32	33	4 – 43
1020237	5.37	13	2 – 930
1020241	5.57	28	4 - 1,610
1020226	5.64	17	2 - 1,610
1020225	6.06	19	2 – 590

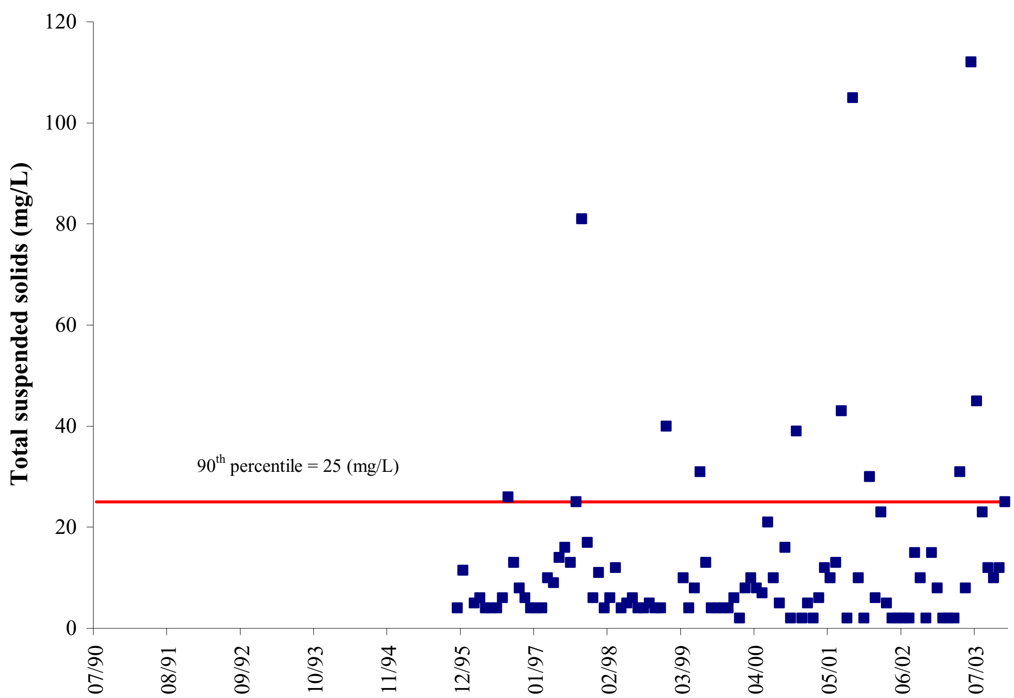

Figure 7.51 TSS concentrations at DMME MPID 1020127.

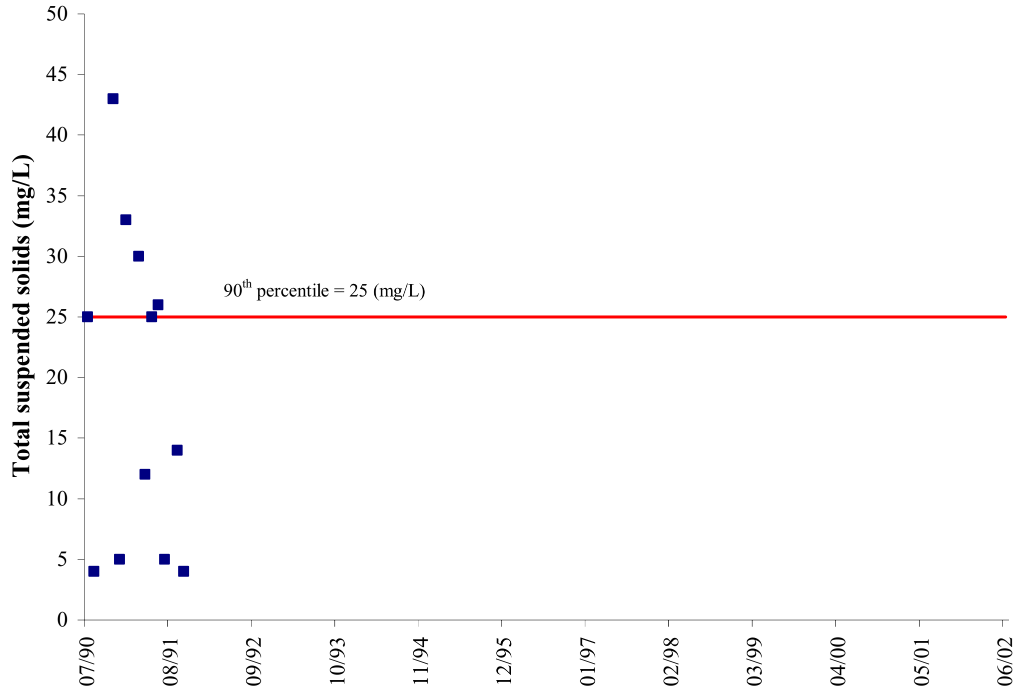

Figure 7.52 TSS concentrations at DMME MPID 1020209.

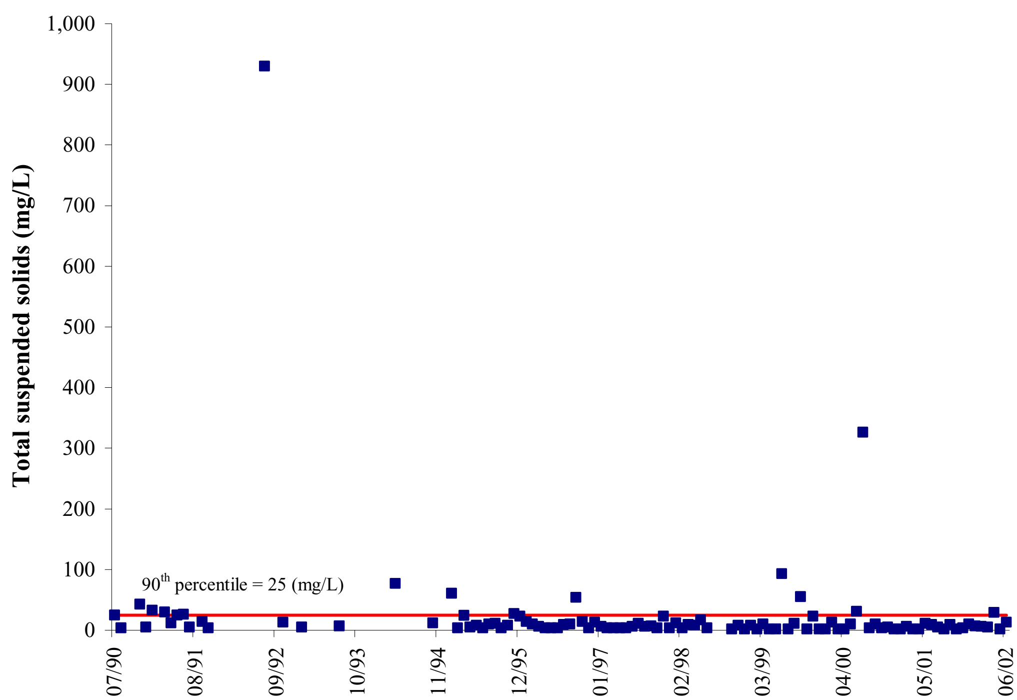

Figure 7.53 TSS concentrations at DMME MPID 1020237.

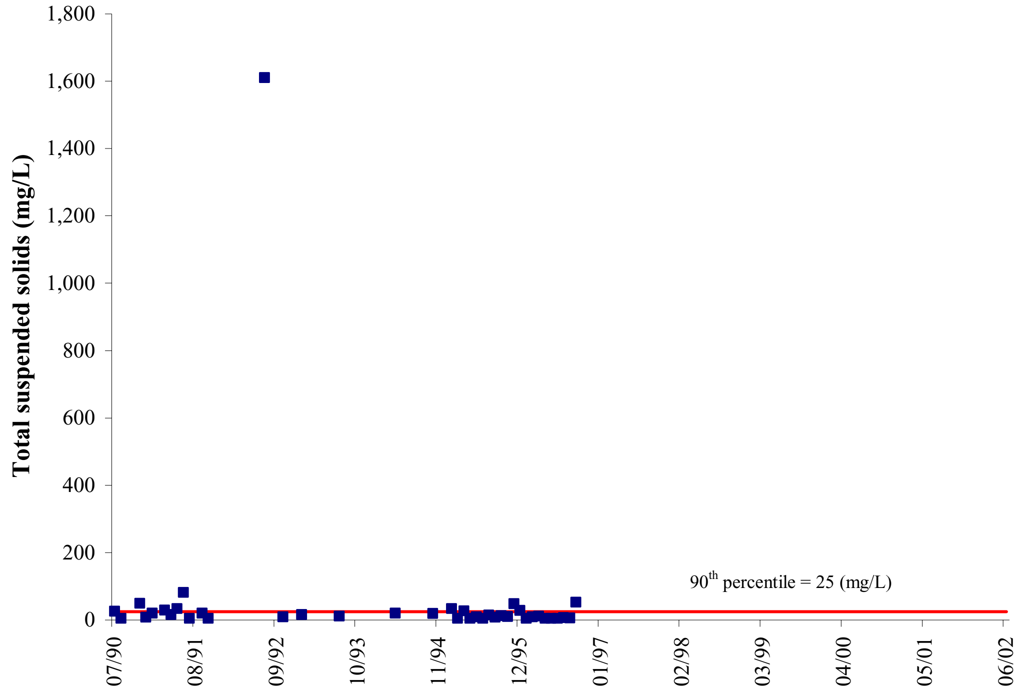

Figure 7.54 TSS concentrations at DMME MPID 1020241.

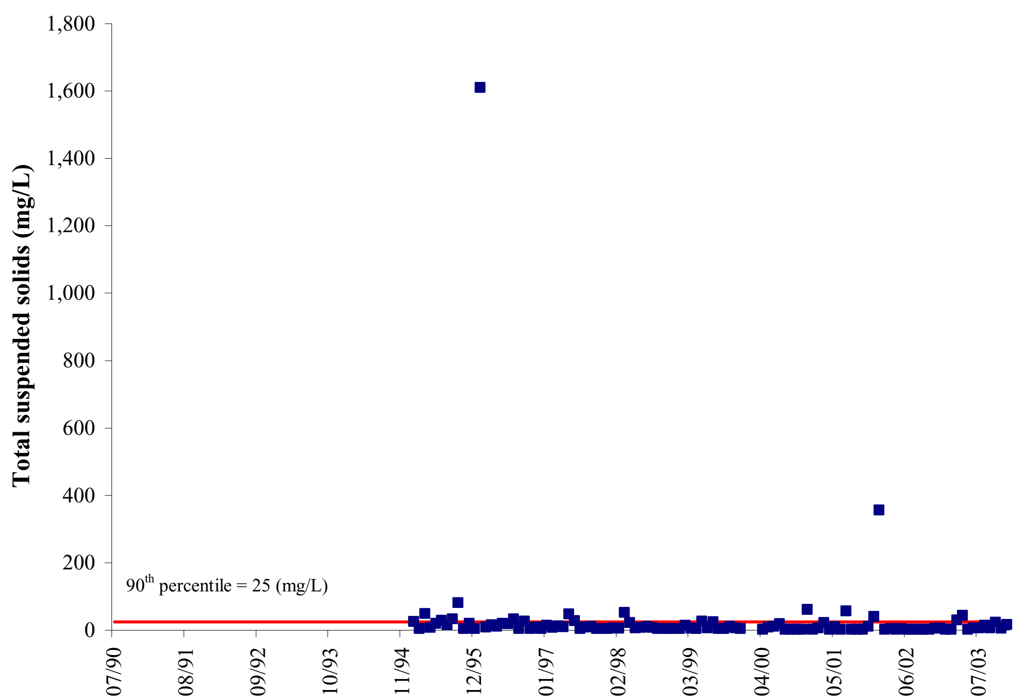

Figure 7.55 TSS concentrations at DMME MPID 1020226.

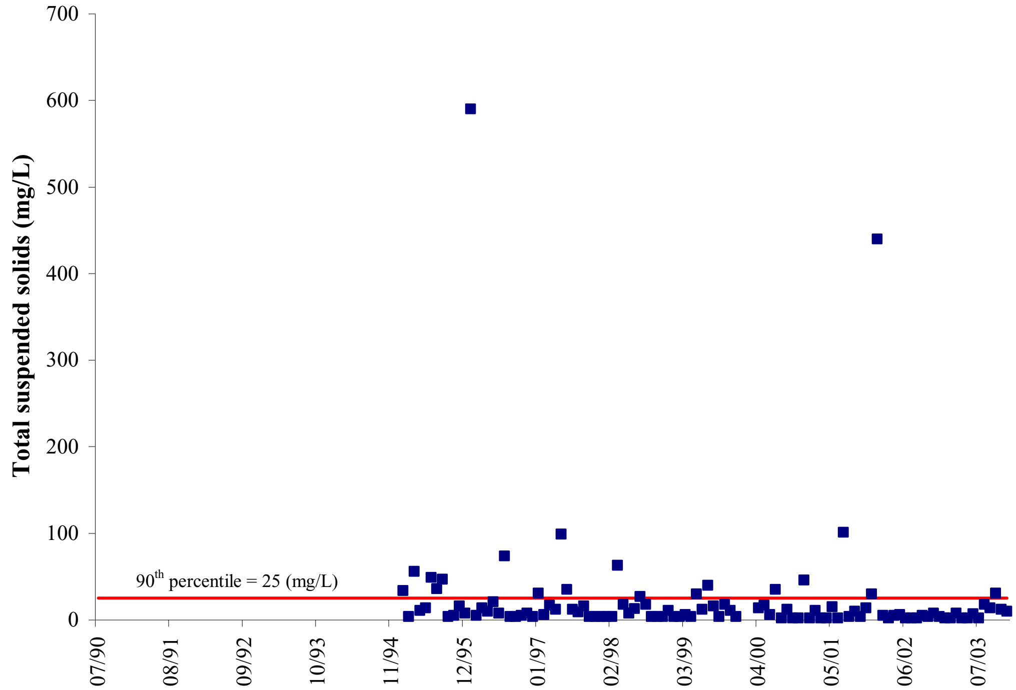

Figure 7.56 TSS concentrations at DMME MPID 1020225.

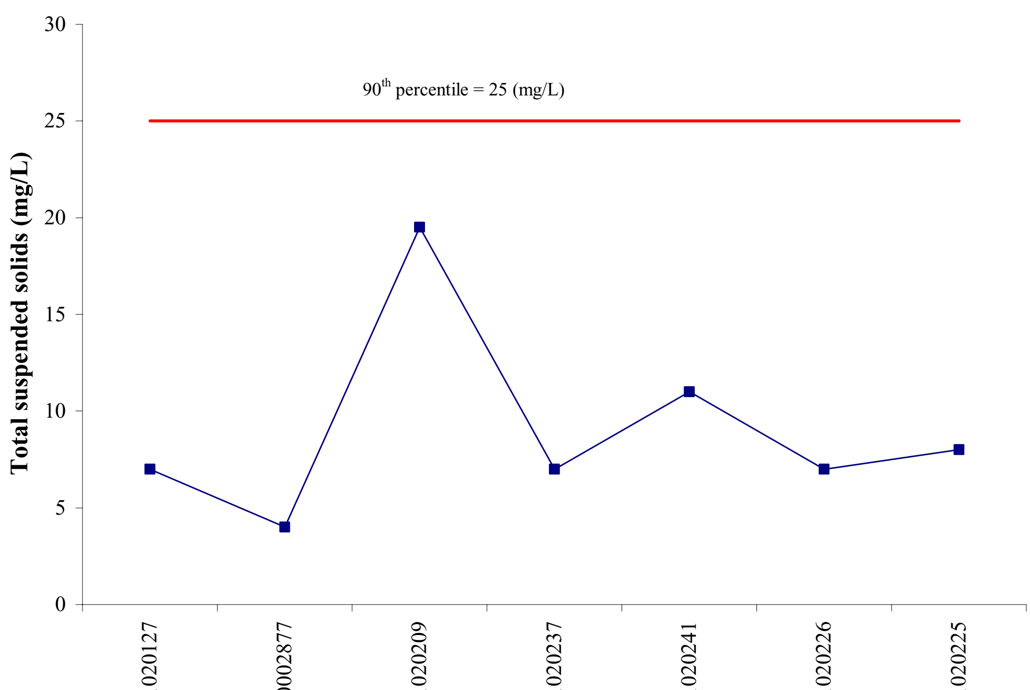

Figure 7.57 Median TSS concentrations at DMME MPIDs on Straight Creek.

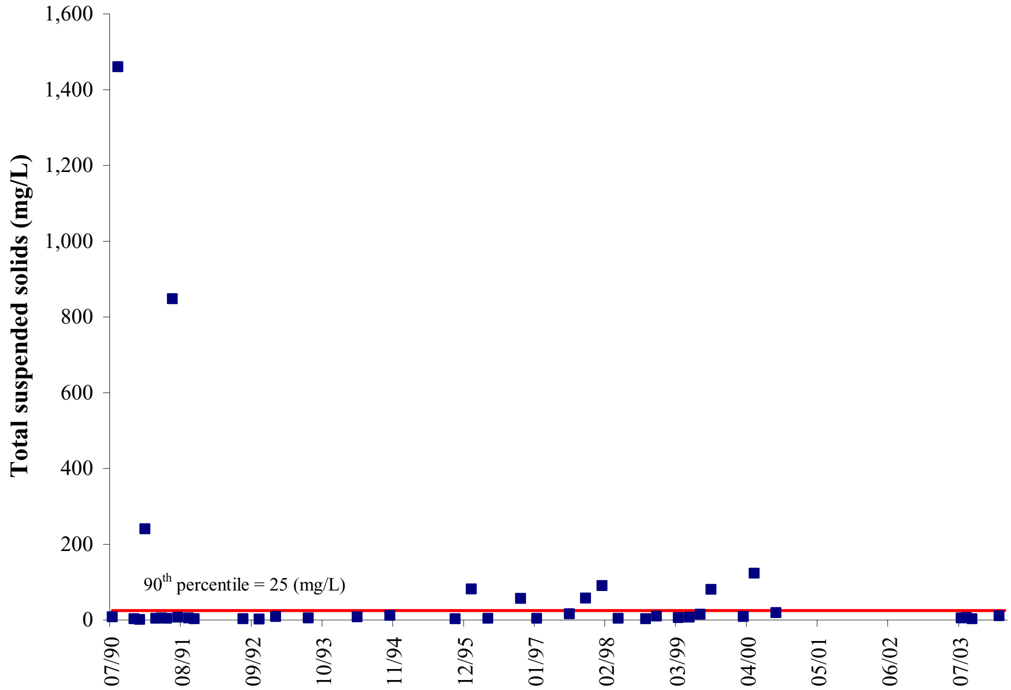

Figure 7.58 TSS concentrations at VADEQ station 6BSRA001.11.

Turbidity was sampled at the VADEQ stations and there were excessive values at station 6BSRA001.11 (Figure 7.59). Median turbidity values for the VADEQ stations are shown in Figure 7.60.

TSS concentrations at both the VADEQ station and the DMME MPIDs clearly show a pattern of periodic excess concentrations. Habitat scores from the seven VADEQ benthic surveys at station 6BSRA000.40 between 1991 and 1999 demonstrate that sediment is a problem in Straight Creek. Based on the high TSS concentrations and turbidity values, and consistently low habitat scores sediment is a probable stressor.

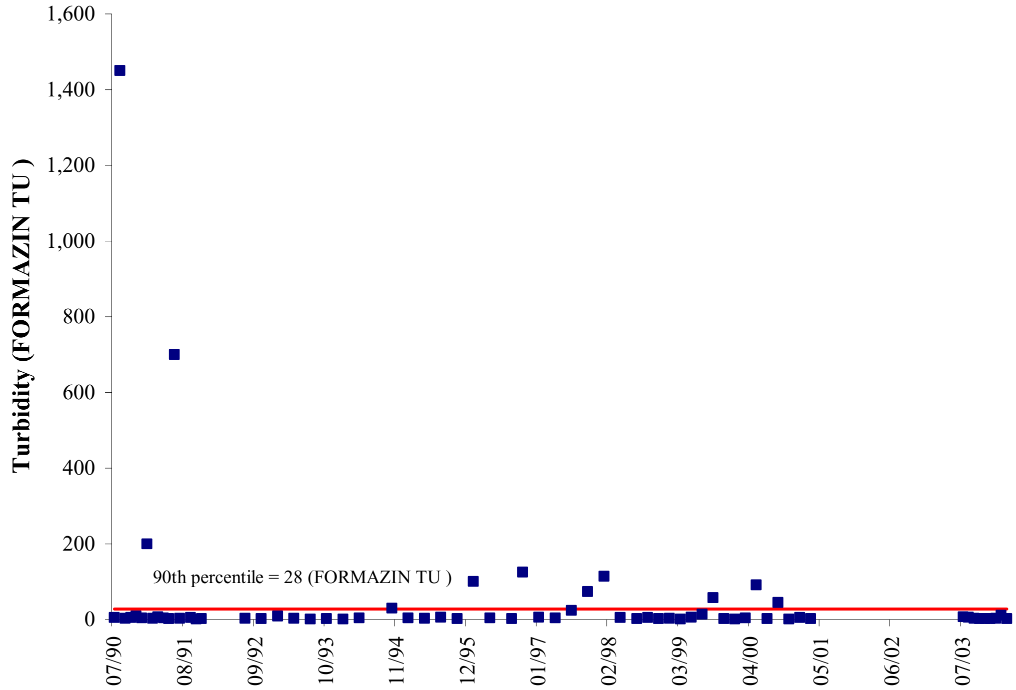

Figure 7.59 Turbidity values at VADEQ station 6BSRA001.11.

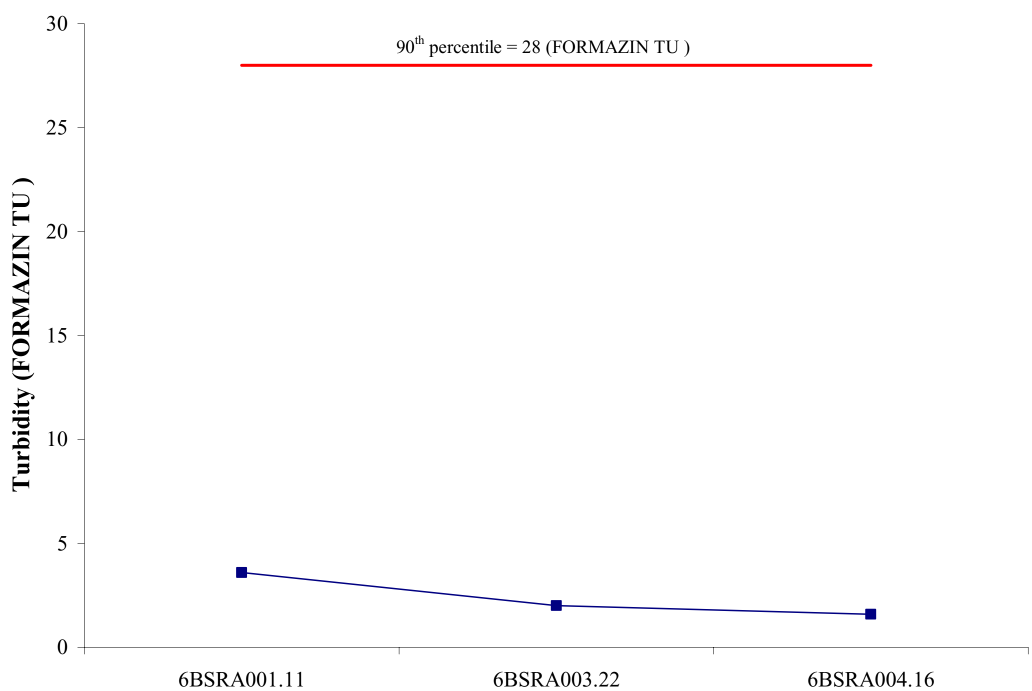

Figure 7.60 Median turbidity values at VADEQ stations on Straight Creek.

Coal mining is a major land use in the Straight Creek watershed and a recent study by the United States Geological Survey (USGS, 20011) noted that this activity results in the moving of significant amounts of earth and rock that alters the chemistry and geomorphology of the watershed. As water percolates through this unconsolidated material TDS, conductivity, and sulfate values will likely increase. The fracturing of rock also increases the transport and deposition of fine-grained material into the stream, reducing the quality and quantity of available habitat for benthic macroinvertebrates (USGS, 2001). The data in this chapter indicate that sediment and TDS are the stressors most responsible for the benthic impairment in Straight Creek. A preliminary draft of this chapter was sent to the EPA for review and comment. The review was done at the EPA Region 3 office in Wheeling, West Virginia and they noted that the selection of the most probably stressors in particular TDS was definitely correct (Pond, 2005). The EPA further noted that addressing a pollutant like TDS was, "definitely going in the right direction to improve aquatic life in this watershed." It is acknowledged that there have been four significant pollution events in the past nine years. Some were related to current mining operations and some to historic mining activities (see Chapter 6). These incidents may have played a role in the depression of the benthic community in Straight Creek.

MapTech received additional data from Biological Monitoring, Inc. (BMI) on January 10, 2005. The data consisted of benthic monitoring performed by BMI at six locations on Straight Creek (10/97 – 9/1998) and additional chemical data (10/1996 – 12/1998) collected by Lone Mountain Processing, Inc. (LMPI). The benthic data was assessed using the West Virginia Stream Condition Index (WVASCI). All six biological monitoring sites showed consistent impairment based on the WVASCI. The chemical monitoring data was very similar to the data supplied by DMME that was discussed in Chapter 6. The analysis of this data did not alter the decision that sediment and TDS are the probable stressors in Straight Creek.

8. REFERENCE WATERSHED SELECTION

A reference watershed approach was used to estimate the necessary load reductions that are needed to restore a healthy aquatic community and allow the streams in the Powell River watershed to achieve their designated uses. This approach is based on selecting a non-impaired watershed that has similar land use, soils, stream characteristics (*e.g.*, stream order, corridor, slope), area (not to exceed double or be less than half that of the impaired watershed), and is in the same ecoregion as the impaired watershed. The modeling process uses load rates or pollutant concentrations in the non-impaired watershed as a target for load reductions in the impaired watershed. The impaired watershed is modeled to determine the current load rates and establish what reductions are necessary to meet the load rates of the non-impaired watershed.

Eight potential reference watersheds were selected from the Central Appalachians and the Valley and Ridge ecoregions for analyses that would lead to the selection of a reference watershed for Straight Creek (Figure 8.1). These watersheds include Dismal Creek in Buchanan County, Indian Creek and Middle Creek in Tazewell County, the McClure River and Fryingpan Creek in Dickenson County, the South Fork Powell River in Wise County, Stoney Creek in Scott County, and Martin Creek in Lee County. The potential reference watersheds were ranked based on quantitative and qualitative comparisons of watershed attributes (*e.g.*, land use, soils, slope, stream order, watershed size). Based on these comparisons and after conferring with state and regional VADEQ personnel, Middle Creek watershed, Tazewell County was selected as the reference watershed for the streams in the Powell River watershed.

Middle Creek watershed is a good choice as the reference watershed, as information that is needed to select numeric endpoints is readily available from water quality monitoring performed by DMME. The Middle Creek watershed has a history of mining activity and has recovered from a benthic impairment. Computer simulation models have been developed to simulate flow, TDS concentrations, and sediment loads in Middle Creek. In addition, the necessary reductions in loadings to the impaired streams can be shown as achievable targets, as exemplified by the improvement in water quality of Middle Creek.

Figure 8.2 shows the location of Straight Creek and Middle Creek within the ecoregion. Figure 8.3 compares the land use distributions between the watersheds. Figure 8.4 shows the soils in the watersheds. Table 8.1 compares soil characteristics between the watersheds.

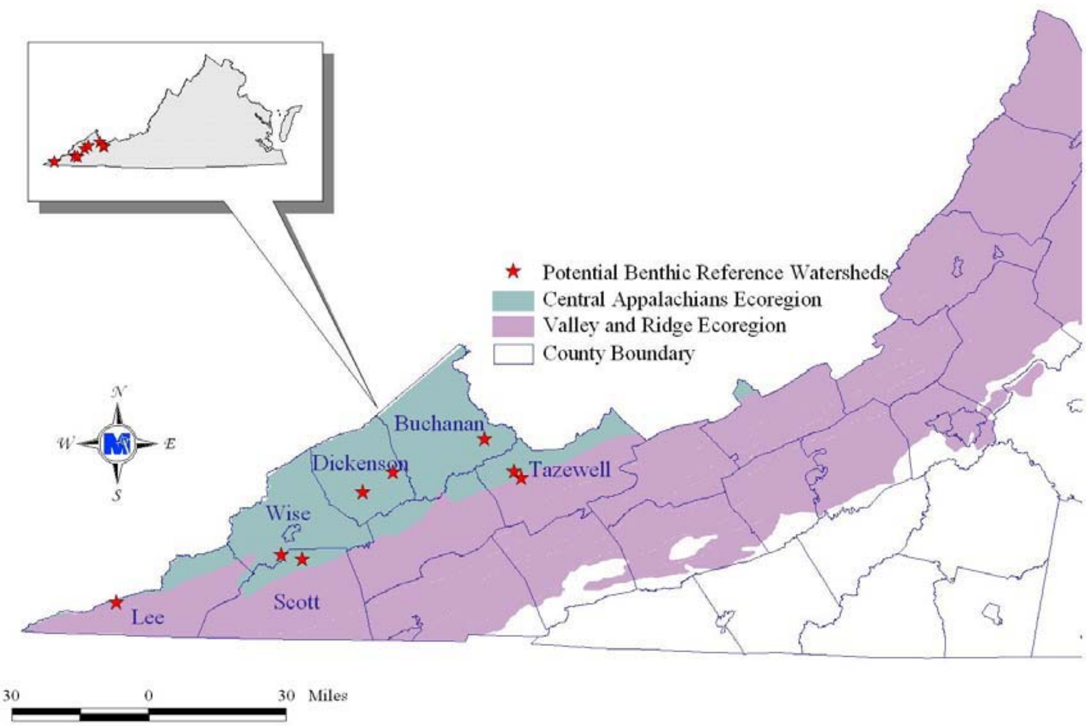

Figure 8.1 Location of potential reference watersheds.

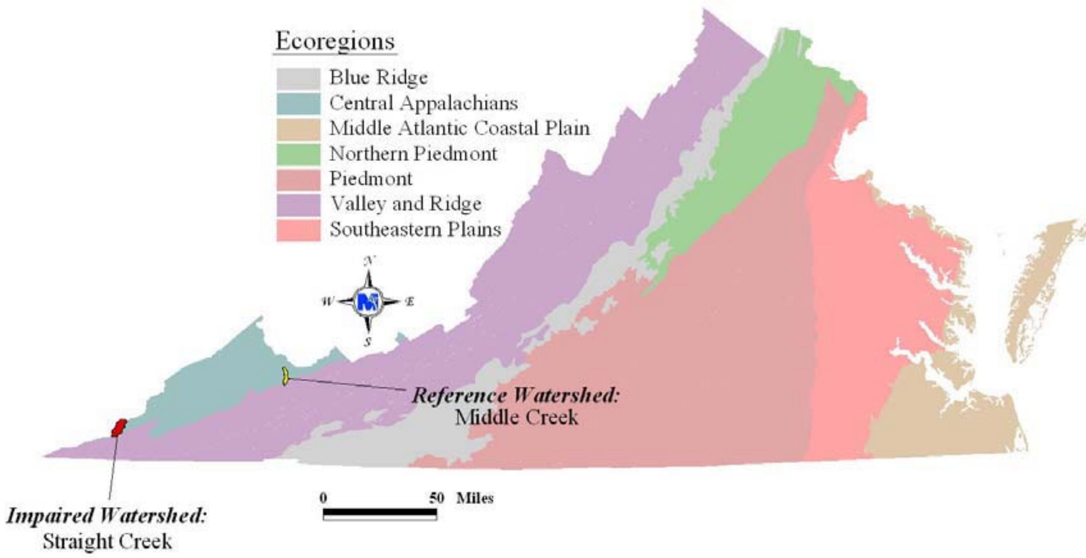

Figure 8.2 Location of impaired and reference watershed within ecoregion.

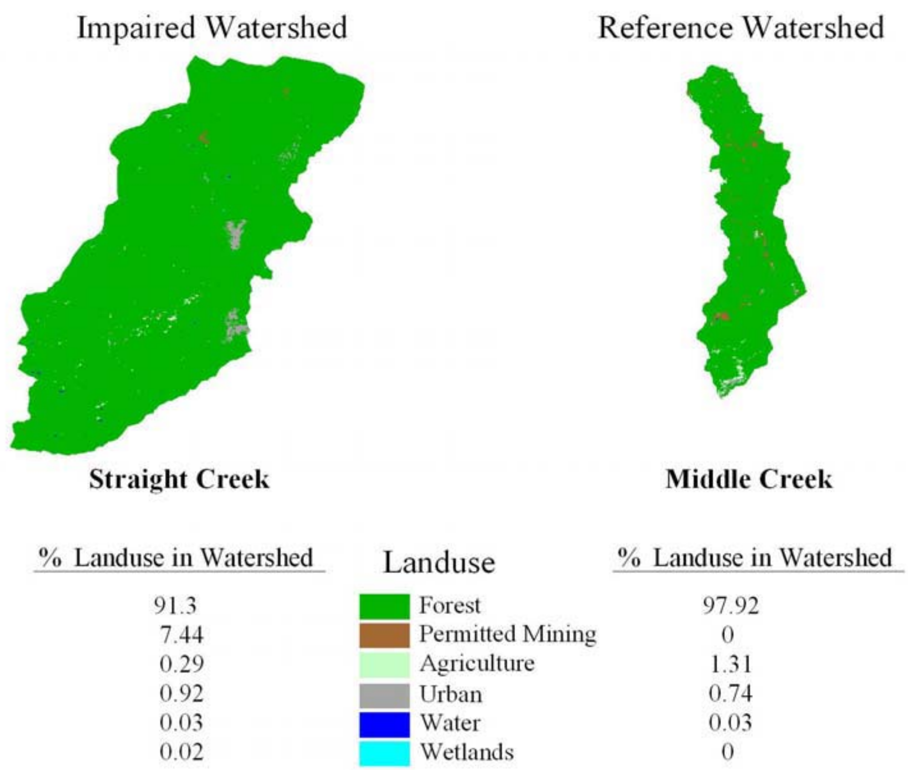

Figure 8.3 Straight Creek and Middle Creek land use comparisons.

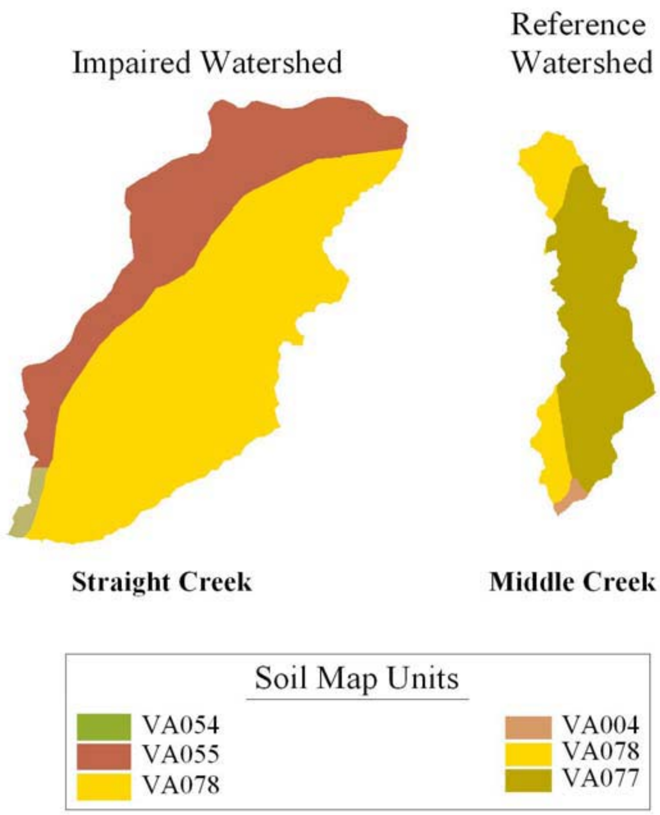

Figure 8.4 Straight Creek and Middle Creek soil comparisons.

Table 8.1 Straight Creek and Middle Creek soil characteristics.

Soil Characteristic	Straight Creek	Middle Creek
Hydrologic Group	B	B
Slope (degrees) (area weighted values)	20.58	20.89
Erodibility Factor (K) (area weighted values)	0.203	0.270
Soil Moisture Capacity (in) (area weighted values)	0.233-1.243	0.216-1.047

This page intentionally left blank.

9. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of a TMDL for the Straight Creek watershed, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored water quality data were then used to verify that the relationships developed through modeling were accurate. In this section, the selection of modeling tools, parameter development, calibration, and model application for TDS and sediment are discussed.

As described in Chapter 8 of this document, Middle Creek in Tazewell County, VA was selected as the reference watershed. Using a reference watershed with a history of coal mining and benthic impairment ensures that the TDS and sediment TMDLs developed for Straight Creek are achievable scenarios. The 90th percentile recorded TDS concentration since the delisting of Middle Creek (334 mg/L) and the average annual sediment load from the Middle Creek watershed were used to define the benthic TMDL loads for the Straight Creek watershed.

9.1 Modeling Framework Selection

9.1.1 HSPF - TDS

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions and to perform the TDS TMDL allocations. The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed consideration of seasonal aspects of precipitation patterns within the watershed. The mining land uses within a subwatershed that discharged surface runoff were collectively modeled as a separate RCHRES, with appropriate characteristics to model the detention time associated with the structures. It was assumed that all runoff from active mining was controlled by one of these structures (Section 4.2.1). The HSPF hydrology model is explained in Chapter 4.

9.1.2 GWLF - Sediment

A reference watershed approach was used in this study to develop benthic TMDLs for sediment for the Straight Creek watershed. As noted in Chapter 7 sediment was identified as a probable stressor for Straight Creek. A watershed model was used to simulate sediment loads from potential sources in Straight Creek, and the Middle Creek reference watershed. The model used in this study was the Visual *Basic™* version of the Generalized Watershed Loading Functions (GWLF) model with modifications for use with ArcView (Evans et al., 2001). The model also included modifications made by Yagow et al., 2002 and BSE, 2003. Numeric endpoints were based on unit-area loading rates calculated for the reference watershed. The TMDLs were then developed for the impaired watershed based on these endpoints and the results from load allocation scenarios.

The GWLF model was developed at Cornell University (Haith and Shoemaker, 1987; Haith, et al., 1992) for use in ungaged watersheds. It was chosen for this study as the model framework for simulating sediment. GWLF is a continuous simulation, spatially lumped model that operates on a daily time step for water balance calculations and monthly calculations for sediment and nutrients from daily water balance. In addition to runoff and sediment, the model simulates dissolved and attached nitrogen and phosphorus loads delivered to streams from watersheds with both point and nonpoint sources of pollution. The model considers flow input from both surface and groundwater. Land use classes are used as the basic unit for representing variable source areas. The calculation of nutrient loads from septic systems, stream-bank erosion from livestock access, and the inclusion of sediment and nutrient loads from point sources are also supported. Runoff is simulated based on the Soil Conservation Service's Curve Number method (SCS, 1986). Erosion is calculated from a modification of the Universal Soil Loss Equation (USLE) (Schwab et al., 1981; Wischmeier and Smith, 1978). Sediment estimates use a delivery ratio based on a function of watershed area and erosion estimates from the modified USLE. The sediment transported depends on the transport capacity of runoff.

For execution, GWLF uses three input files for weather, transport, and nutrient loads. The weather file contains daily temperature and precipitation for the period of record. Data are based on a water year typically starting in April and ending in March. The transport file contains input data related to hydrology and sediment transport. The nutrient file contains primarily nutrient values for the various land uses, point sources, and septic system types, but does include urban sediment buildup rates.

9.2 Model Setup

9.2.1 HSPF – TDS

No deep mine discharges were present in the Straight Creek and North Fork Powell River watersheds during the hydrology calibration period. TDS loads were incorporated into the HSPF models calibrated for hydrology for Straight Creek. TDS was modeled as a conservative constituent. The pathways for delivery to the stream are transport with surface runoff, interflow, and groundwater. Sensitivity analyses were performed on the TDS model to ascertain how the model responds to changes in each parameter.

9.2.2 GWLF - Sediment

Watershed data needed to run GWLF used in this study were generated using GIS spatial coverage, local weather data, streamflow data, literature values, and other data. Watershed boundaries for the impaired stream segment and the selected reference watershed were delineated from USGS 7.5 minute digital topographic maps using GIS techniques. The reference watershed outlet for Middle Creek was located at biological monitoring station 6BMID000.20 just upstream of the confluence with the Clinch River. For TMDL development, the total area for the Middle Creek reference watershed was equated with the area of Straight Creek watershed. To accomplish this, the area of land use categories in reference watershed Middle Creek, was proportionately increased based on the percentage land use distribution. As a result, the watershed area for Middle Creek was increased to be equal to the watershed areas for the Straight Creek watershed. After adjustment, the distribution of land use remained the same as pre-adjustment values.

The GWLF was developed to simulate runoff, sediment and nutrients in ungaged watersheds based on landscape conditions such as land use/landcover, topography, and soils. In essence, the model uses a form of the hydrologic units (HU) concept to estimate runoff and sediment from different pervious areas (HUs) in the watershed (Li, 1975; England, 1970). In the GWLF model, the nonpoint source load calculation for sediment is affected by land use activity (*e.g.,* farming practices), topographic parameters, soil characteristics, soil cover conditions, stream channel conditions, livestock access, and weather. The model uses land use categories as the mechanism for defining homogeneity of source areas. This is a variation of the HU concept, where homogeneity in hydrologic response or nonpoint source pollutant response would typically involve the identification of soil land use topographic conditions that would be expected to give a homogeneous response to a given rainfall input. A number of parameters are included in the model to index the affect of varying soil-topographic conditions by land use entities. A description of model parameters is given in Section 9.2.2.1 followed by a description of how parameters and other data were calculated and/or assembled.

9.2.2.1 Description of GWLF Model Input Parameters

The following description of GWLF model input parameters was taken from a TMDL Draft report prepared by BSE, 2003.

Hydrologic Parameters

Watershed Related Parameter Descriptions

- <u>*Unsaturated Soil Moisture Capacity (SMC):*</u> *The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute – available water capacity.*

- <u>*Recession Coefficient (/day):*</u> *The recession coefficient is a measure of the rate at which streamflow recedes following the cessation of a storm, and is approximated by averaging the ratios of streamflow on any given day to that on the following day during a wide range of weather conditions, all during the recession limb of each storm's hydrograph.*

- <u>*Seepage Coefficient (/day):*</u> *The seepage coefficient represents the amount of flow lost to deep seepage.*

Running the model for a 3-month period prior to the chosen period during which loads were calculated, initialized the following parameters.

- *<u>Initial unsaturated storage (cm):</u> Initial depth of water stored in the unsaturated (surface) zone.*

- *<u>Initial saturated storage (cm):</u> Initial depth of water stored in the saturated zone.*

- *<u>Initial snow (cm):</u> Initial amount of snow on the ground at the beginning of the simulation.*

- *<u>Antecedent Rainfall for each of 5 previous days (cm):</u> The amount of rainfall on each of the five days preceding the first day in the weather files.*

Month Related Parameter Descriptions

- *<u>Month</u>: Months were ordered, starting with April and ending with March – in keeping with the design of the GWLF model and its assumption that stored sediment is flushed from the system at the end of each Apr-Mar cycle. Model output was modified in order to summarize loads on a calendar year basis.*

- *<u>ET CV:</u> Composite evap-transpiration cover coefficient, calculated as an area-weighted average from land uses within each watershed.*

- *<u>Hours per Day:</u> mean number of daylight hours.*

- *<u>Erosion Coefficient:</u> This a regional coefficient used in Richard's equation for calculating daily erosivity. Each region is assigned separate coefficients for the months October-March, and for April-September.*

Sediment Parameters

Watershed-Related Parameter Descriptions

- *<u>Sediment Delivery ratio:</u> The fraction of erosion – detached sediment – that is transported or delivered to the edge of the stream, calculated as the inverse function of watershed size (Evans et al., 2001).*

Land use-Related Parameter Descriptions

- *<u>USLE K-factor (erodibility):</u> The soil erodibility factor was calculated as an area weighted average of all component soil types.*

- *<u>USLE LS-factor:</u> This factor is calculated from slope and slope length.*

- *<u>USLE C-factor:</u> The vegetative cover factor for each land use was evaluated following GWLF manual guidance and Wischmeier and Smith (1978).*

- *<u>Daily sediment build-up rate on impervious surfaces</u>: The daily amount of dry deposition deposited from the air on impervious surfaces on days without rainfall, assigned using GWLF manual guidance.*

Streambank Erosion Parameter Descriptions (Evans, 2002)

- *<u>% Developed Land:</u> Percentage of the watershed with urban-related land uses- defined as all land in MDR, HDR, and COM land uses, as well as the impervious portions of LDR.*

- *<u>Animal density:</u> Calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by watershed area in acres.*

- *<u>Stream length:</u> Calculated as the total stream length of natural stream channel, in meters. Excludes the non-erosive hardened and piped sections of the stream.*

- *<u>Stream length with livestock access:</u> calculated as the total stream length in the watershed where livestock have unrestricted access to streams, resulting in streambank trampling, in meters.*

9.3 Source Representation

9.3.1 Total Dissolved Solids (TDS)

Nonpoint sources were modeled as having four potential delivery pathways, delivery with surface runoff, delivery through interflow, delivery through groundwater, and delivery through point sources. Pollutants associated with interflow and/or groundwater were modeled by assigning a constant concentration for each in a particular PERLND. Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.,* existence of control structures). Depending on the timeframe of the simulation being run, the model was varied appropriately. Data representing the water quality calibration periods were used to develop the model used in this study.

9.3.1.1 TDS Point Sources and Permitted Sources

There were no deep mine discharges in the Straight Creek watershed during the water quality calibration time period. TDS loading from uncontrolled discharges (straight pipes) was applied directly to the stream in the model. The TDS concentration from human waste from uncontrolled discharges was estimated as 500 mg/L (Metcalf and Eddy, 1991).

Runoff from surface mine areas is collected in ponds. These ponds are considered permitted discharges since the mining industry and DMME are required to monitor the outflow. As discussed in Chapter 4, a runoff event is necessary to transport TDS from the land to the pond water. The mining ponds were assumed not to reduce the TDS load from the collected water and all TDS in runoff from mining land uses was routed to the stream via the ponds.

9.3.1.2 TDS Nonpoint Sources

Nonpoint source contributions from the fourteen land use categories (Table 4.1) were assumed to be delivered to the stream flow system in surface runoff, interflow and groundwater. The HSPF model was used to link pollutants from nonpoint sources with downstream water quality.

9.3.1.3 Road Salt Applications

Annual road salt application rates for Lee (Straight Creek) County were provided by the Virginia Department of Transportation (VDOT). The road salt applications were deposited on paved roads in the watershed on days with recorded snowfall. The daily rate was calculated using a ratio of snowfall on a given day to the total snowfall during the modeling time period. This was done to simulate the practice of applying less salt for light snowfall and more salt during heavy snow events. These daily salt applications were used to estimate TDS in surface runoff from paved roads during the winter months. The road salt applications were modeled using an external time series depositing on the paved road PERLNDs in the watershed.

9.3.2 Sediment

Three source areas identified as the primary contributors to sediment loading in the Straight Creek watershed include surface runoff, point sources, and streambank erosion. The sediment process is continual but is often accelerated by human activity. An objective of the TMDL process is to minimize this acceleration. This section describes predominant sediment source areas, model parameters, and input data needed to simulate sediment loads.

9.3.2.1 Surface Runoff - Sediment

During runoff events (natural rainfall or irrigation), sediment is transported to streams from pervious land areas (*e.g.,* agricultural fields, lawns, forest.). Rainfall energy, soil cover, soil characteristics, topography, and land management affect the magnitude of sediment loading. Agricultural management activities such as overgrazing (particularly on steep slopes), high tillage operations, livestock concentrations (*e.g.,* along stream edge, uncontrolled access to streams), forest harvesting, land disturbance due to mining and construction (roads, buildings, etc.) all tend to accelerate erosion at varying degrees. During dry periods, sediment from air or traffic builds up on impervious areas and is transported to streams during runoff events. The magnitude of sediment loading from this source is affected by various factors (*e.g.,* the deposition from wind erosion and vehicular traffic).

The mining ponds were assumed to reduce the TSS load from the collected water, therefore, the effluent from all mining land was assumed to deliver only the permitted 70 mg/L TSS to the stream for all storm events.

9.3.2.2 Channel and Streambank Erosion

An increase in impervious land without appropriate stormwater control increases runoff volume and peaks, which leads to greater channel erosion potential. It has been well documented that livestock with access to streams can significantly alter physical dimensions of streams through trampling and shearing (Armour et al., 1991; Clary and Webster, 1989; Kaufman and Kruger, 1984). Increasing the bank full width decreases stream depth, increases sediment, and adversely affects aquatic habitat (USDI, 1998).

9.3.2.3 TSS Point Sources

Fine sediments are included in TSS loads that are permitted for various facilities with wastewater and industrial stormwater VPDES permits within the Straight Creek watershed. In the Straight Creek watershed, there is one permitted construction stormwater discharge. There were no MS4 permits located in the Straight Creek watershed. Sediment loads from permitted wastewater and industrial stormwater dischargers are included in the WLA component of the TMDL, in compliance with 40 CFRξ130.2(h). The TSS loading from uncontrolled discharges (straight pipes) was accounted for in the GWLF model results. A TSS concentration from human waste was estimated as 320 mg/L (Lloyd, 2004).

9.4 Selection of Representative Modeling Period

Selection of the modeling period was based on three factors; availability of data (discharge and water quality), the degree of land-disturbing activity, and the need to represent critical hydrological conditions. Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Using observed data that is reported at a shorter time-step improves this process and subsequently the performance of a time-dependent model.

Water quality data were collected from Straight Creek on a monthly basis. Water quality (TDS) data were available in the period from 7/11/1990 through 3/4/2004 at various locations throughout the watershed (Table 9.1).

As described in Chapter 4, the primary limiting factor in determining a modeling period was selection of a timeframe with relatively stable land use and manmade hydraulics. Since there was a limited amount of data for the impairment during the identified period of relative stability, it was determined that the modeling effort would be more successful if all of these data were used for calibration, rather than dividing the dataset into smaller datasets for calibration and validation.

Table 9.1 Summary of modeling time periods for Straight Creek.

Impairment	Hydrology Calibration - HSPF	TDS Calibration - HSPF	Hydrology Calibration - GWLF
Straight Creek	10/1/1991 to 3/31/1995	10/1/1992 to 9/30/1996	10/1/1991 to 3/31/1995

9.5 Sensitivity Analysis

9.5.1 Sensitivity Analysis - HSPF

Sensitivity analyses were conducted to assess the sensitivity of the model to changes in water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.,* seasonal and spatial variability of TDS loading).

For the water quality sensitivity analyses, an initial base run was performed during the calibration time period. Descriptions of the three parameters adjusted for the water quality sensitivity analyses with base values for the model runs given are presented in Table 9.2.

Table 9.2 Base parameter values used to determine water quality model response for Straight Creek.

Parameter	Description	Units	Base Value
IOQC	TDS in interflow	mg/ft^3	20,000.00
AOQC	TDS in groundwater flow	mg/ft^3	20,000.00
WSQOP	wash-off rate for TDS on land surface	in/hr	1.64

The three parameters were increased and decreased by amounts that were consistent with the range of values for the parameter. The model's responses to these changes are shown in Table 9.3.

Table 9.3 Percent change in average monthly TDS (mg/L) for Straight Creek.

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly TDS mg/L for 1992-1996					
		Jan	Feb	Mar	Apr	May	Jun
IOQC	-50	-25.82	-26.81	-27.43	-25.34	-25.59	-20.12
IOQC	-10	-5.16	-5.36	-5.49	-5.07	-5.12	-4.02
IOQC	10	5.16	5.36	5.49	5.07	5.12	4.02
IOQC	50	25.82	26.81	27.43	25.34	25.59	20.12
AOQC	-50	-21.87	-21.05	-20.35	-22.50	-22.28	-26.22
AOQC	-10	-4.37	-4.21	-4.07	-4.50	-4.46	-5.24
AOQC	10	4.37	4.21	4.07	4.50	4.46	5.24
AOQC	50	21.87	21.05	20.35	22.50	22.28	26.22
WSQOP	-50	-0.01	0.00	0.10	-0.03	0.00	0.00
WSQOP	-10	0.00	0.00	0.02	-0.01	0.00	0.00
WSQOP	10	0.00	0.00	-0.01	0.01	0.00	0.00
WSQOP	50	0.00	0.01	-0.06	0.06	0.01	0.00

Table 9.3 Percent change in average monthly TDS (mg/L) for Straight Creek (continued).

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly TDS mg/L for 1992-1996					
		Jul	Aug	Sept	Oct	Nov	Dec
IOQC	-50	-16.03	-16.43	-15.57	-15.71	-18.85	-21.49
IOQC	-10	-3.21	-3.29	-3.11	-3.14	-3.77	-4.30
IOQC	10	3.21	3.29	3.11	3.14	3.77	4.30
IOQC	50	16.03	16.43	15.57	15.71	18.85	21.49
AOQC	-50	-29.31	-29.33	-29.55	-31.25	-28.69	-26.06
AOQC	-10	-5.86	-5.87	-5.91	-6.25	-5.74	-5.21
AOQC	10	5.86	5.87	5.91	6.25	5.74	5.21
AOQC	50	29.31	29.33	29.55	31.25	28.69	26.06
WSQOP	-50	0.17	0.08	0.08	0.01	-0.05	0.05
WSQOP	-10	0.03	0.02	0.01	0.00	-0.01	0.01
WSQOP	10	-0.02	-0.02	-0.01	0.00	0.01	-0.01
WSQOP	50	-0.10	-0.09	-0.05	-0.02	0.04	-0.02

9.5.2 Sensitivity Analysis - GWLF

Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.*, seasonal and spatial variability of land disturbance, runoff curve number, etc.). Sensitivity analyses were run on the runoff curve number (CN) and the combined erosion factor (KLSCP), which combines the effects of soil erodibility, land slope, land cover, and management practices (Table 9.5). For a given simulation, the model parameters in Table 9.5 were set at the base value except for the parameter being evaluated. The parameters were adjusted to -10%, and 10% of the base value. Results are listed in Table 9.6. The results show that the parameters are directly correlated with runoff and sediment load. The relationships show fairly linear responses, with outputs being slightly more sensitive to changes in CN than KLSCP. The results tend to reiterate the need to carefully evaluate conditions in the watershed and follow a systematic protocol in establishing values for model parameters.

Table 9.4 Base watershed parameter values used to determine hydrologic and sediment response for Straight Creek.

Land use	Straight Creek	
	CN	KLSCP
Abandoned Mine Lands	76.86	0.52
Commercial Impervious	98.00	-
Commercial Pervious	93.76	0.012
Cropland	70.63	2.62
Forest	61.44	0.013
Forest Disturbed	70.74	1.03
Pasture/Hay	70.84	0.067
Permitted Mining:		
Reclaimed Mine Area[1]	71.29	0.18
Active Mine Area	85.72	4.42
Residential Impervious	98.00	-
Residential Pervious	70.09	0.016
Water	100	-

[1]values from Barfield et al., 1983.

Table 9.5 Sensitivity of GWLF model response to changes in selected parameters for Straight Creek.

Model Parameter	Parameter Change (%)	Change in Runoff (%)	Change in Sediment Load (%)
CN	10	9.76	19.57
CN	-10	-5.78	-9.10
KLSCP	10	0.00	10.01
KLSCP	-10	0.00	-9.99

9.6 Model Calibration of HSPF - TDS

Calibration is performed in order to ensure that the model accurately represents the water quality processes in the watershed. Hydrology calibration for Straight Creek was discussed in Chapter 4. Through calibration, water quality parameters were adjusted within appropriate ranges until the model performance was deemed acceptable.

Water quality calibration is complicated by a number of factors, some of which are described here. First, water quality concentrations are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters such as TDS concentration. Additionally, the limited amount of measured data for use in calibration impedes the calibration process.

The water quality (TDS) calibration of Straight Creek used TDS data from 10/1/1992 through 9/30/1996. Three parameters were utilized for model adjustment: concentration in interflow (IOQC), concentration in groundwater (AOQC), and rate of surface runoff of concentration from land surfaces (WSQOP). Changes in the IOQC and WSQOP parameters change TDS levels during runoff events, while changes in AOQC effect base flow TDS concentrations All of these parameters were initially set at acceptable levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled TDS concentrations was established (Table 9.6). Careful visual inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. Results of the calibration are presented in Figures 9.1 through 9.3.

Table 9.6 Model parameters utilized for water quality calibration of Straight Creek.

Parameter	Units	Initial Parameter Estimate	Calibrated Parameter Value
WSQOP	in/hr	1.64	1.64
IOQC	mg/ft^3	20,000	5,250 – 475,000
AOQC	mg/ft^3	20,000	5,750 – 800,000

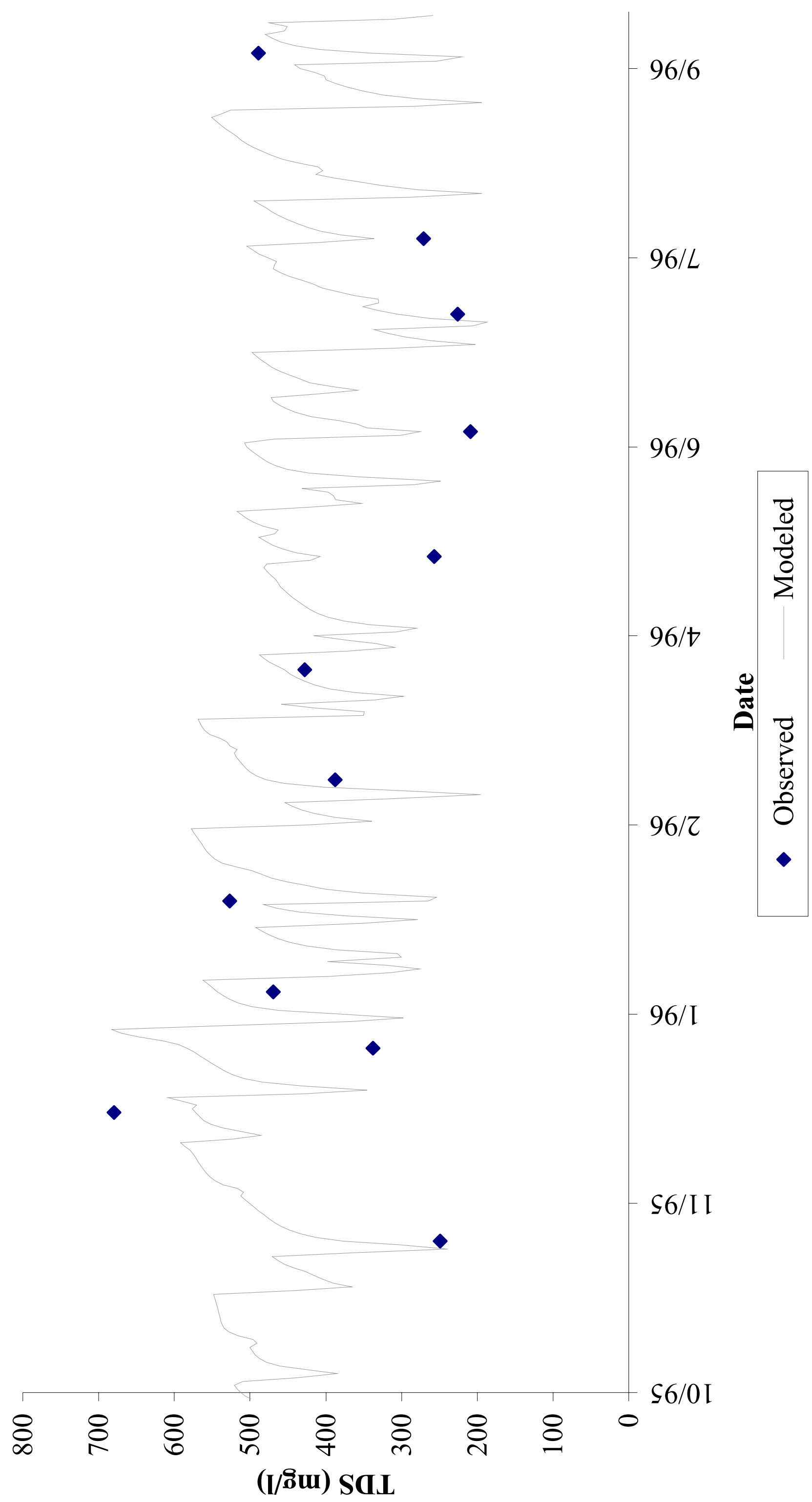

Figure 9.1 Mean daily modeled TDS concentrations compared to instantaneous observed TDS concentrations for subwatershed 6 in the Straight Creek impairment, during the calibration period.

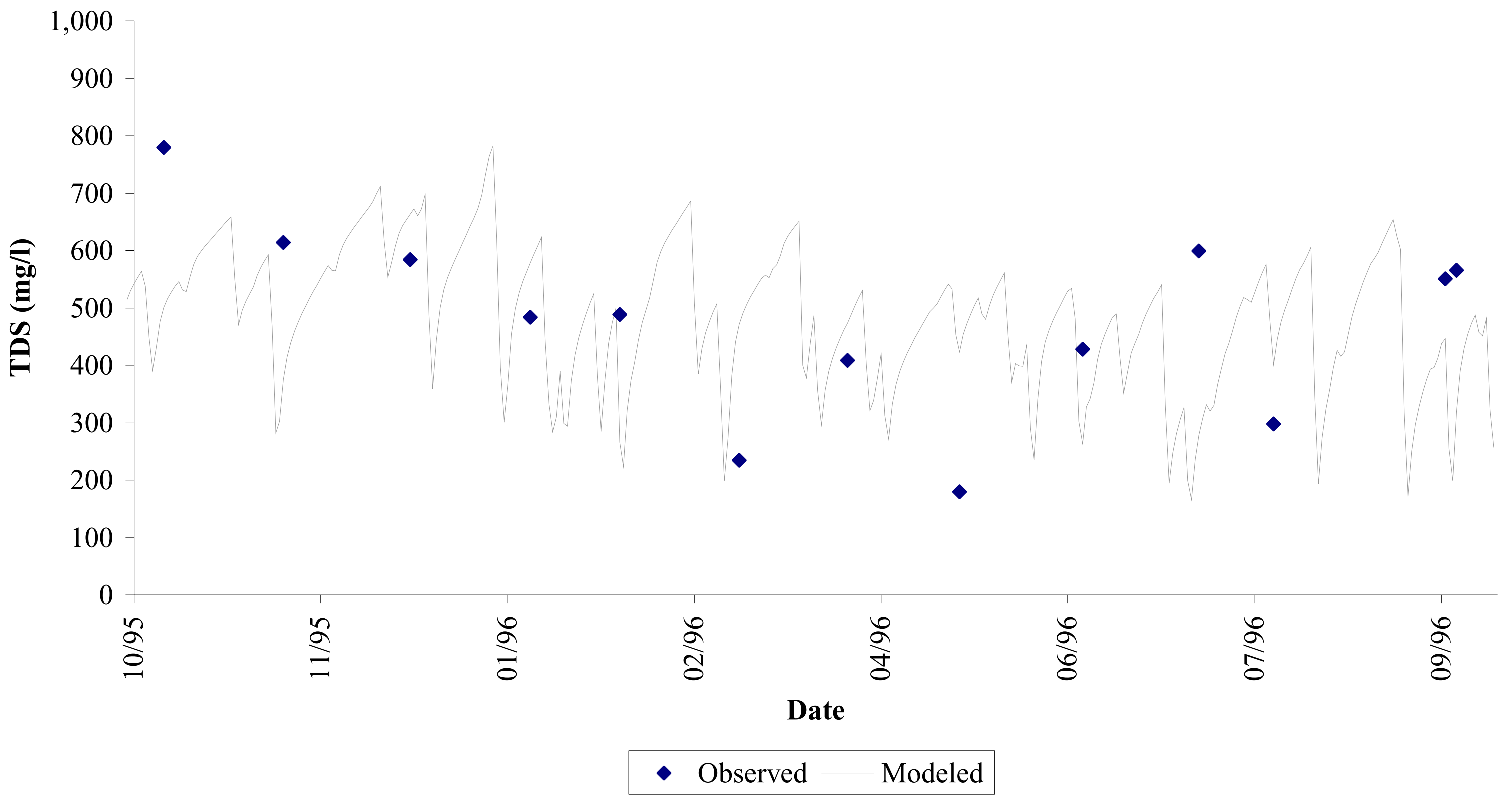

Figure 9.2 Mean daily modeled TDS concentrations compared to instantaneous observed TDS concentrations for subwatershed 7 in the Straight Creek impairment, during the calibration period.

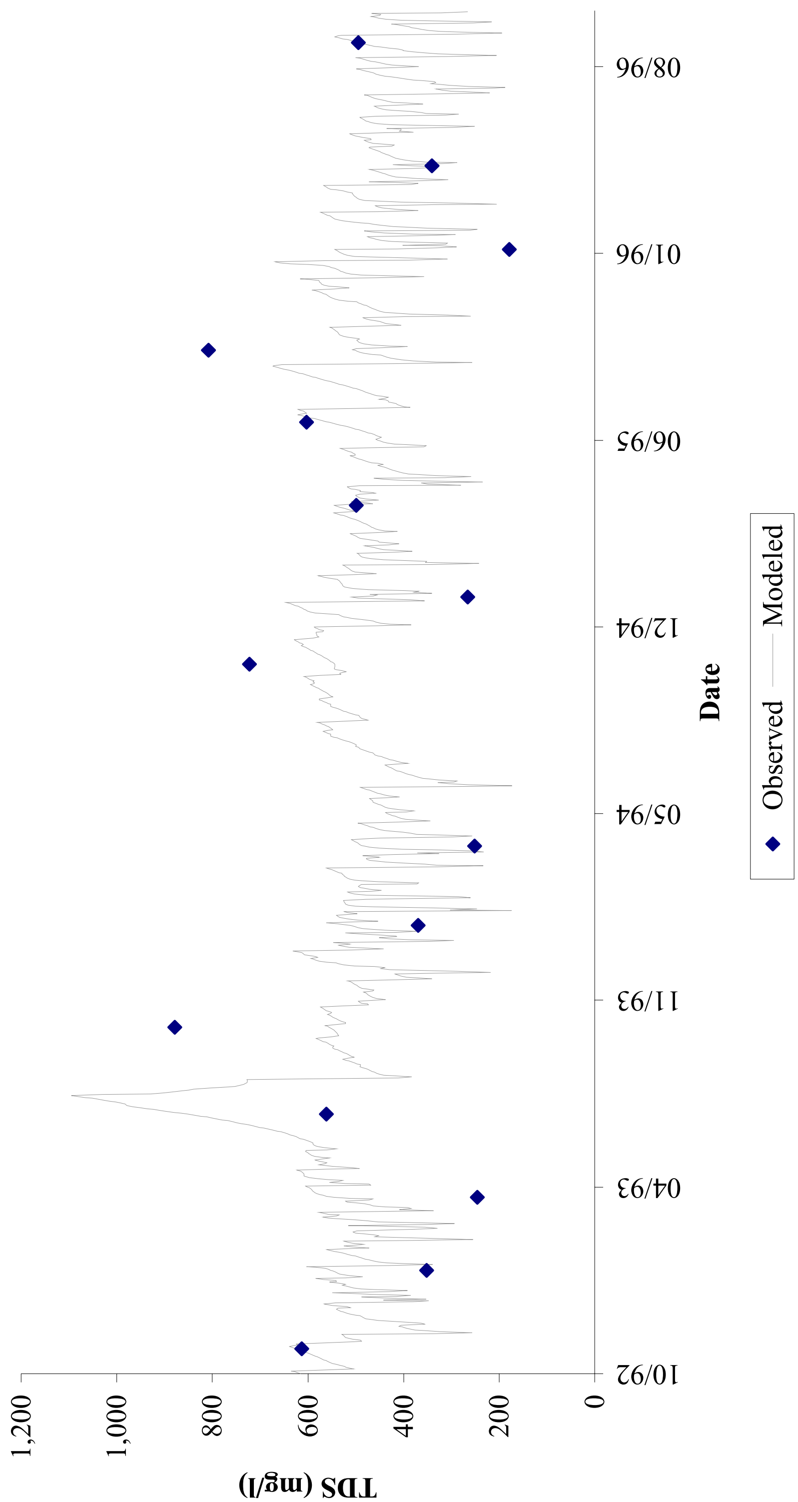

Figure 9.3 Mean daily modeled TDS concentrations compared to instantaneous observed TDS concentrations for subwatershed 8 in the Straight Creek impairment, during the calibration period.

9.7 Model Calibration of GWLF - Hydrology and Sediment

Although the GWLF model was originally developed for use in ungaged watersheds, calibration was performed to ensure that hydrology was being simulated accurately. This process was preferred in order to minimize errors in sediment simulations due to potential gross errors in hydrology. The model's parameters were assigned based on available soils, land use, and topographic data. Parameters that were adjusted during calibration included the recession constant, the evapotranspiration cover coefficients, the unsaturated soil moisture storage, and the seepage coefficient.

9.7.1 Middle Creek

The final hydrologic calibration results for Middle Creek are displayed in Figures 9.4 and 9.5 for the calibration period with statistics showing the accuracy of fit given in the Table 9.8. The reference watershed, Middle Creek, did not have an observed streamflow station located within the watershed boundary. Precipitation and temperature data were obtained from NCDC station 447174 in Richlands, VA. The model for Middle Creek was calibrated using the mean monthly flow simulated from the HSPF model for the period 10/1/1995 through 9/30/1999.

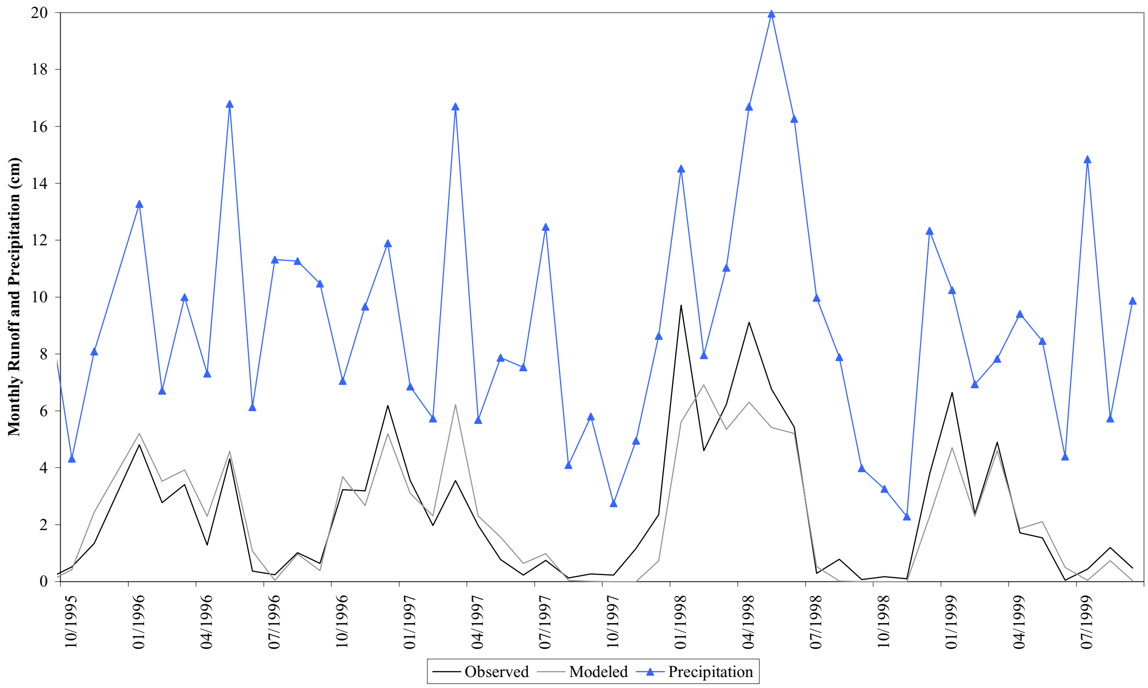

Figure 9.4 Comparison of monthly GWLF simulated (Modeled) and HSPF simulated (Observed) for the Middle Creek watershed.

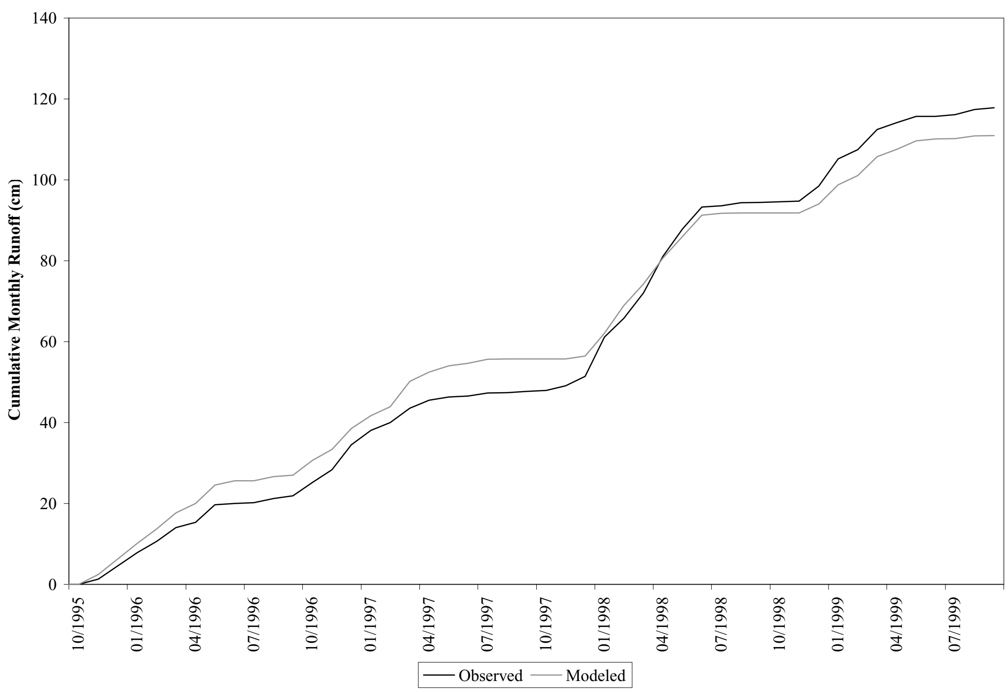

Figure 9.5 Comparison of cumulative monthly GWLF simulated (Modeled) and HSPF simulated (Observed) for the Middle Creek watershed.

9.7.2 Straight Creek

The model for Straight Creek was calibrated using simulated flow from the calibrated hydrology HSPF model for the period October 1, 1991 through March 31, 1995. Precipitation and temperature data were obtained from NCDC station 446626 with some adjustments from IFLOWs stations close to Straight Creek watershed. The final calibration results for Straight Creek are given in the Figures 9.6 and 9.7 with accuracy of fit statistics given in Table 9.7.

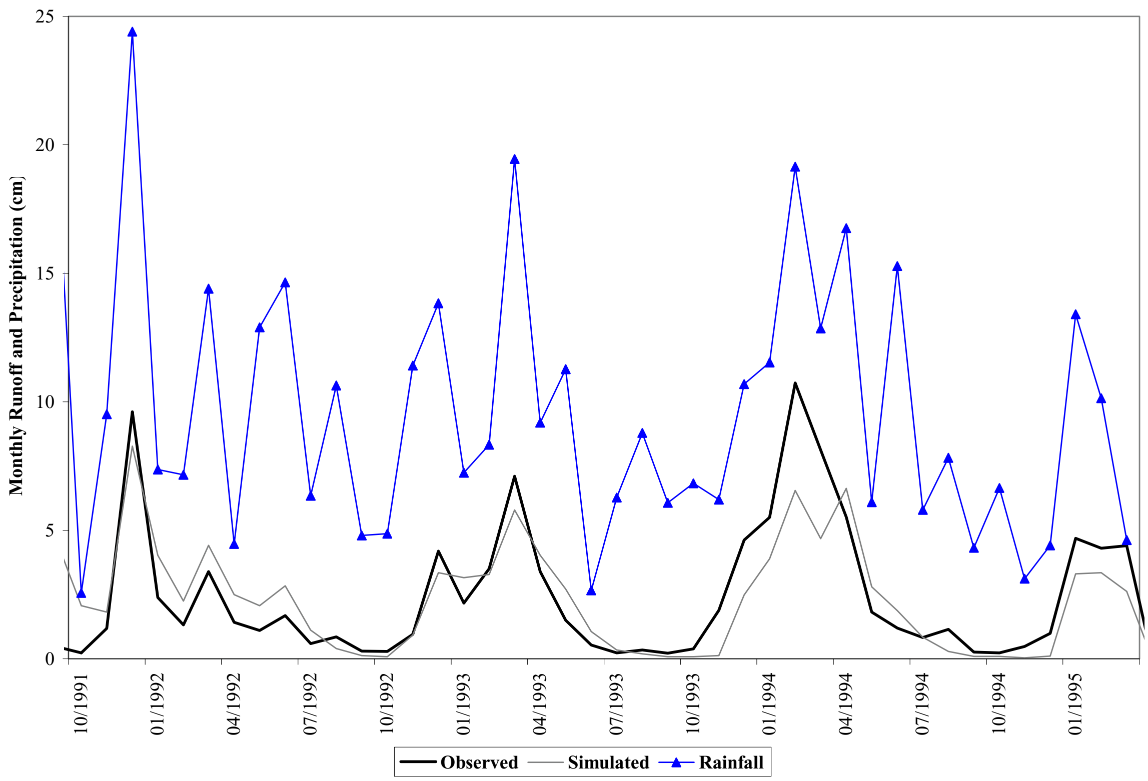

Figure 9.6 Comparison of monthly GWLF simulated (Modeled) and HSPF simulated (Observed) for the Straight Creek watershed.

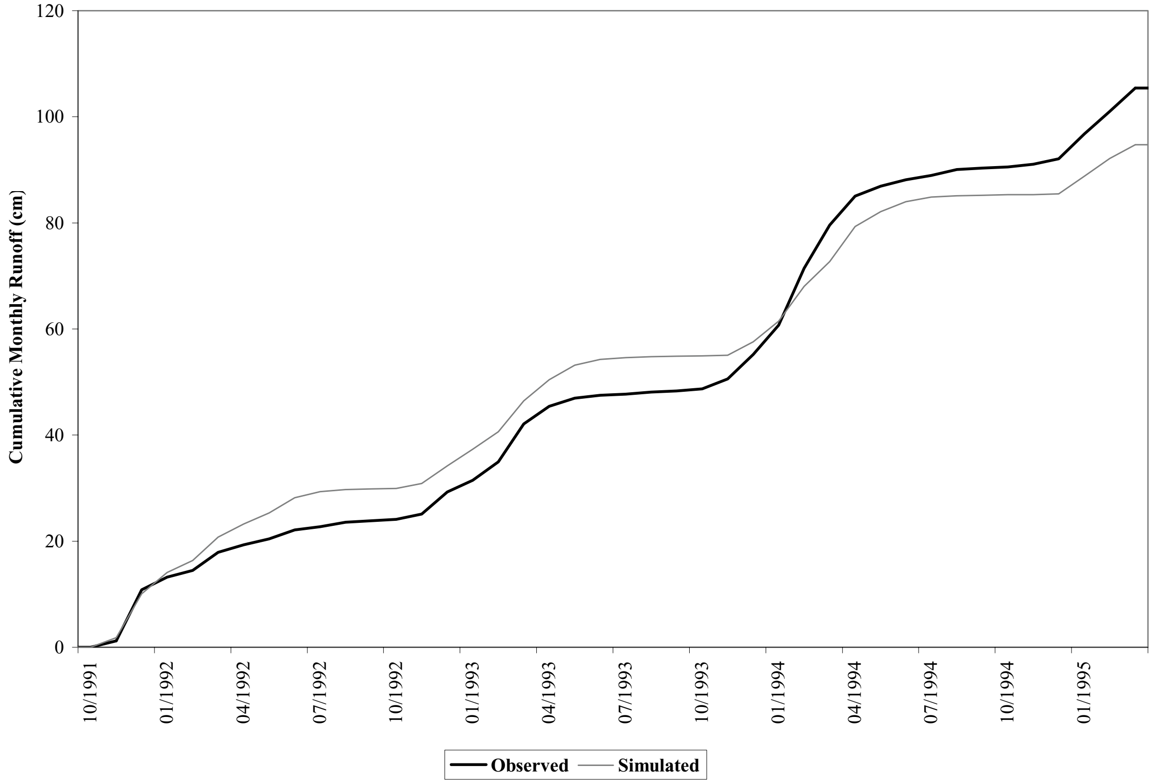

Figure 9.7 Comparison of cumulative monthly GWLF simulated (Modeled) and HSPF simulated (Observed) for the Straight Creek watershed.

9.7.3 GWLF Hydrology Calibration Statistics

Model calibrations were considered good to excellent for total runoff volume (Table 9.7). Monthly fluctuations were variable but were still reasonably good considering the general simplicity of GWLF. Results were also consistent with other applications of GWLF in Virginia (*e.g.,* Tetra Tech, 2001 and BSE, 2003).

Table 9.7 GWLF flow calibration statistics for Straight Creek and Middle Creek.

Watersheds	Simulation Period	R^2 Correlation value	Total Volume Error (Sim-Obs)
Straight Creek	10/1/1991 – 3/31/1995	0.880	-0101
Middle Creek	10/1/1995 – 9/30/1999	0.893	-0.058

9.8 Existing Conditions - GWLF

A listing of parameters from the GWLF transport input files that were finalized during hydrologic calibration for conditions existing at the time of impairment are given in Tables 9.8 through 9.10. Watershed parameters for Straight Creek, and reference watershed Middle Creek are given in Table 9.8. Monthly evaporation cover coefficients are listed in Table 9.9.

Table 9.8 GWLF watershed parameters for existing conditions in the impaired and reference watersheds.

GWLF Watershed Parameter	Units	Straight Creek	Middle Creek
Recession Coefficient	Day^{-1}	0.15	0.052
Seepage Coefficient	Day^{-1}	0.0291	0.062
Sediment Delivery Ratio	---	0.13	0.13
Unsaturated Water Capacity	(cm)	9.94	7.440
Erosivity Coefficient (Apr-Sep)	---	0.25	0.25
Erosivity Coefficient (Oct-Mar)	---	0.06	0.06
% Developed land	(%)	0.138	0.225
Livestock density	(AU/ac)	0.0001	0.0000
Area-weighted soil erodibility (K)	---	0.198	0.270
Area weighted runoff curve number	---	66.50	68.90
Total Stream Length	(m)	101,354	15,840
Mean channel depth	(m)	5.14	0.9

Table 9.9 Straight Creek and reference watershed Middle Creek GWLF monthly evaporation cover coefficients for existing conditions.

Watershed	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Straight Creek	0.32	0.79	0.89	0.897	0.897	0.89	0.79	0.42	0.42	0.42	0.32	0.32
Middle Creek	0.68	0.70	0.82	0.88	0.88	0.71	0.70	0.66	0.65	0.65	0.65	0.66

Table 9.10 lists the area-weighted USLE erosion parameter and runoff curve number by land use erosion source areas for Straight Creek and the reference watershed Middle Creek. The loads from permitted mine lands were modeled by multiplying the runoff volume by the maximum permitted TSS concentration.

Table 9.10 GWLF land use parameters for existing conditions in the impaired and reference watersheds.

Land use	Straight Creek		Middle Creek	
	CN	KLSCP	CN	KLSCP
Abandoned Mine Lands	76.86	0.52		
Commercial Impervious	98.00	-	98.00	-
Commercial Pervious	93.76	0.012	93.67	0.026
Cropland	70.63	2.62	80.80	3.19
Forest	61.44	0.013	65.05	0.014
Forest Disturbed	70.74	1.03	73.37	1.10
Pasture/Hay	70.84	0.067	70.63	0.036
Permitted Mining:				
Reclaimed Mine Area[1]	71.29	0.18		
Active Mine Area	85.72	4.42		
Reclaimed Mine Area-not permitted[1]			65.38	0.39
Residential Impervious	98.00	-	98.00	-
Residential Pervious	70.09	0.016	70.30	0.012
Water	100	-	100	-

[1]values from Barfield et al., 1983.

The area adjustments for the reference watershed compared to Straight Creek are listed in Table 9.11.

Table 9.11 Land use areas for the impaired, reference, and area-adjusted reference watersheds.

		Reference Watershed	
Sediment Source	Straight Creek (ha)	Middle Creek (ha)	Middle Creek Area-Adjusted (ha)
Abandoned Mine Lands	805.7	0.00	0.00
Commercial Impervious	5.88	6.50	16.05
Commercial Pervious	1.04	1.10	2.83
Cropland	4.23	13.40	33.04
Forest	5,838	2,623	6,487
Forest Disturbed	29.92	81.10	200.6
Pasture/Hay	17.82	23.70	58.52
Permitted Mining:			
Reclaimed Mine Area	304.2	0.00	
Active Mine Area	6.98	0.00	
Reclaimed Mine Area-not permitted	0.00	98.70	244.2
Residential Impervious	6.98	1.60	4.08
Residential Pervious	51.15	12.10	29.90
Water	79.38	29.80	73.71

[1] 1ha = 2.47 ac

The sediment loads existing at the time of impairment were modeled for Straight Creek and the reference watershed Middle Creek. The existing condition for the Straight Creek watershed is the combined sediment load, which compares to the target TMDL load under existing conditions for the area-adjusted reference watershed Middle Creek (Table 9.12). The target sediment TMDL load for Straight Creek is the average annual load in metric tons per year (Mg/yr) from the area-adjusted Middle Creek watershed under existing conditions minus the Margin of Safety (MOS) (Table 9.12).

Table 9.12 Existing sediment loads for the impaired and area-adjusted reference watersheds.

Sediment Source	Straight Creek (Mg/yr)	Straight Creek (Mg/ha/yr)	Reference Watershed Middle Creek (Mg/yr)	Reference Watershed Area-Adjusted (Mg/ha/yr)
Abandoned Mine Lands	15,014	18.63	0.00	0.00
Commercial Impervious	1.33	0.23	3.51	0.22
Commercial Pervious	0.61	0.59	2.22	0.79
Cropland	375.2	88.60	2,245	67.95
Forest	2,207	0.38	669.1	0.10
Forest Disturbed	1,040	34.78	3,495	17.42
Pasture/Hay	40.59	2.28	25.53	0.44
Reclaimed Mine Area-not permitted	0.00	0.00	951.3	3.90
Residential Impervious	1.58	0.23	0.89	0.22
Residential Pervious	28.25	0.55	3.98	0.13
NPS loads	**18,709**	**146.3**	**7,396**	**91.17**
Permitted Mining:				
Reclaimed mine area	0.39	0.13	0.00	0.00
Active mine area	49.72		0.00	0.00
VAR102252	0.02	0.02		
Straight Pipes	30.55		0.00	0.00
PS loads	**80.68**	**0.15**	**0.00**	**0.00**
Channel Erosion	2.24		1.24	
Watershed Total Loads	**18,792**	**146.4**	**7,398**	**91.2**

10. ALLOCATION

Total Maximum Daily Loads consist of waste load allocations (WLAs, permitted point sources) and load allocations (LAs, nonpoint/non-permitted sources), including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for uncertainties in the process. The definition is typically denoted by the expression:

$$\text{TMDL} = \text{WLAs} + \text{LAs} + \text{MOS}$$

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving water body and still achieve water quality standards. For TDS, the TMDL is expressed in terms of loads (kg/yr). For sediment, the TMDL is expressed in terms of annual load in metric tons per year (Mg/yr).

This section describes the development of TMDLs for TDS and sediment for Straight Creek using a reference watershed approach. The Straight Creek model was run for existing conditions over the period of 10/01/1992 to 9/30/1996 to model TDS and from April 1991 to March 1995 to model sediment losses.

The 90th percentile TDS concentration of 334 mg/L measured in Middle Creek was used as the TMDL endpoint. The average annual sediment load from the Middle Creek reference watershed was used to define the TMDL loads for the Straight Creek watershed.

10.1 Incorporation of a Margin of Safety

In order to account for uncertainty in modeled output, an MOS was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. For example, the typical method of assessing water quality through monitoring involves the collection and analysis of grab samples. The results of water quality analyses on grab samples collected from the stream may or may not reflect the "average" condition in the stream at the time of sampling. Calibration to observed data derived from grab samples introduces modeling uncertainty.

An MOS can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement.

10.2 TDS TMDL

10.2.1 Scenario Development

The allocation scenario was modeled using HSPF. Existing conditions were adjusted until the TMDL endpoint was attained. The TMDL developed for Straight Creek was based on the 90th percentile TDS concentration (334 mg/L) sampled in Middle Creek since biological monitoring indicated that it is not impaired. An implicit MOS was used in the development of this TMDL. By adopting an implicit MOS in estimating the loads in the watershed, it is ensured that the recommended reductions will in fact succeed in meeting the water quality standard.

Pollutant concentrations were modeled over the entire duration of a representative modeling period, and pollutant loads were adjusted until the endpoint was met. The development of the allocation scenario was an iterative process that required numerous runs with each followed by an assessment of source reduction against the water quality target.

10.2.1.1 Wasteload Allocations

In the Straight Creek watershed there are currently no NPDES permitted point sources from deep mining operations.

The NPDES permits associated with surface mining in this watershed was modeled as NPS loads since a runoff event is required to deliver pollutants to the stream from these sources. These sources are considered to be transient as they are temporary best management practices (*e.g.*, ponds) installed to control NPS pollution (mainly sediment) resulting from active surface mining operations. Upon completion of current mining operations, these ponds will likely be removed and additional ponds installed as new operations begin. As such, the wasteload allocation developed for Straight Creek includes a “transient” load, which represents the acceptable load from these sources.

10.2.1.2 Load Allocations

Load allocations to nonpoint sources are divided into land-based loadings from land uses and directly applied loads in the stream (*e.g.,* uncontrolled residential discharges). The TDS loads from straight pipes were modeled as a direct source, but they are not permitted so these loads are included in the LA. Source reductions include those that are affected by both high and low flow conditions. In-stream TDS concentrations are highest during low flow conditions, but TDS concentrations spike during extreme rainfall events (high flow due to runoff).

In the first allocation scenario, uncontrolled residential discharges (*i.e.*, straight pipes) were reduced 100%, but this scenario failed to reduce TDS to the target concentration. Additional scenarios were made by reducing the TDS load in surface runoff (WSQOP), interflow (IOQC), groundwater (AOQC), and direct permitted point sources until the modeled TDS concentration for the modeling period was less than or equal to the target TDS concentration.

10.2.2 TDS TMDL

Table 10.1 shows the final TMDL load for the impairment. Modeling indicated that the stream is most vulnerable to direct discharges during low stream flow conditions. The permitted discharges are listed under the lumped load for WLA allocation. These included all deep mine discharges and surface mine ponds (Table 10.1).

Table 10.1 Average annual TDS loads (kg/yr) modeled after TMDL allocation in the Straight Creek impairment.

Allocation	Description	TDS (kg/year)
***Waste Load Allocation*[1]**		**1.80E+5**
Permit Number	MPID	
Transient Loads[2]		
1100486	*1080828, 1080829, 1080830, 1080832*	
1101320	*1070143, 1070144, 1070145, 1070146, 1070147*	
1201075	*1084495*	
1201079	*1084516*	
1200819	*1084208*	
1200863	*0002021, 0002022, 1070102*	
1201075	*1084494, 1084496*	
1201076	*1084498*	
1201078	*1084498*	
1201079	*1084513, 1084514, 1084515, 1084517*	
1201121	*1070008, 1070009*	
1201286	*1070105, 1070106*	
1201287	*1070109, 1070110, 1070113*	
1201390	*0001380, 1070188, 1070189, 1070190, 1070191, 1070192, 1070193, 1070194, 1070195, 1070196, 1070197, 1070198, 1070199, 1070203, 1070204, 1070205, 1070207, 1070208*	
1201395	*1070234, 1070235, 1070239*	
1201676	*0003097, 0003098*	
1201810	*0004836, 0004837*	
1300627	*1085114, 1085116*	
1300959	*1085330, 1085331*	
1301411	*1070254, 1070255, 1070256, 1070257, 1070258, 1070259, 1070260, 1070261*	
1400357	*0000059, 0001008, 0001630, 1070262, 1085587, 1085588, 1085590, 1085591, 1085593, 1085594, 1085595, 1085596, 1085597, 1085598, 1085602, 1085603*	
1501391	*1070215, 1070216, 1070217*	
	Proposed Permit #1 Spring, 2005	
	Proposed Permit #2 Spring, 2005	
Load Allocation		**8.52E+6**
TMDL		**8.70E+6**

[1] TDS from WLA is presented as a combined load from all permitted sources.
[2] The waste load from runoff-controlling BMPs (*i.e.,* ponds) that are likely to be removed upon completion of current mining operations.

The loads from all land uses impacted by anthropogenic activity (*i.e.,* non-forest and non-wetland areas) were calibrated to meet existing conditions in the stream, and equal reductions were modeled for all land uses impacted by anthropogenic activity. Given the limited amount of data available for parsing the anthropogenic load among known sources, no attempt was made to determine specific load reduction requirements for specific sources.

The waste load allocation was thus established based on overall reductions for the watershed. This approach established an equitable WLA and LA but did not establish a required reduction from permitted sources. At this time, there is not enough water quality and other data on the permitted sources to calculate or model with confidence an existing TDS loading for these facilities. During implementation, the existing permitted sources will be monitored to determine their existing load. Needed reductions cannot be calculated until those data have been collected.

Table 10.2 shows the source loads used for modeling the overall existing and allocation conditions in Straight Creek.

Table 10.2 Source Loads Used in Straight Creek Model Runs.

Source	Total Annual Loading for Existing Conditions (kg/yr)	Total Annual Loading for Allocation Conditions (kg/yr)
Land Based	1.68E+7	8.70E+6
Direct[1]	1.87E+4	0.00E+0

[1] The only direct discharges to Straight Creek are straight pipes during the allocation time period.

Figure 10.1 shows the existing and allocated conditions at the outlet of Straight Creek.

10.2.3 Future Reductions and Future Growth

Before imposing future reductions on permitted sources, VADEQ will reopen and validate or amend the TMDL and subsequently the WQMP regulation, if needed. Amendments may include the quantification of existing loads, % reduction overall or by source subcategory, individual allocations and adjustments of any allocation.

As part of any TMDL reopener, VADEQ will validate or amend, based on all available data and information, its original assumptions about (a) TDS as a most probable stressor; (b) 334 mg/l as the proper water quality target; and (c) the model outputs. To ensure consistency with existing TMDL modification guidance (Guidance Memo 05-2011), if the TMDL reopener occurs in response to a request for additional waste load allocation(s), any cost incurred by the TMDL re-evaluation and remodeling effort will be paid for by the applicant.

New permitted point source discharges will be allowed under the waste load allocation provided they implement applicable VPDES or Virginia Coal Surface Mining Reclamation Regulation (CSMRR) requirements (including any BMP, offset, trading or payment-in-lieu conditions established to meet any future reduction requirements).

Unless and until VADEQ reopens and revises the TMDL to impose TDS wasteload allocations on permitted sources (or categories of sources), new dischargers will be subject to monitor-only requirements, together with whatever permit-based requirements DMME will impose pursuant to the CSMRR.

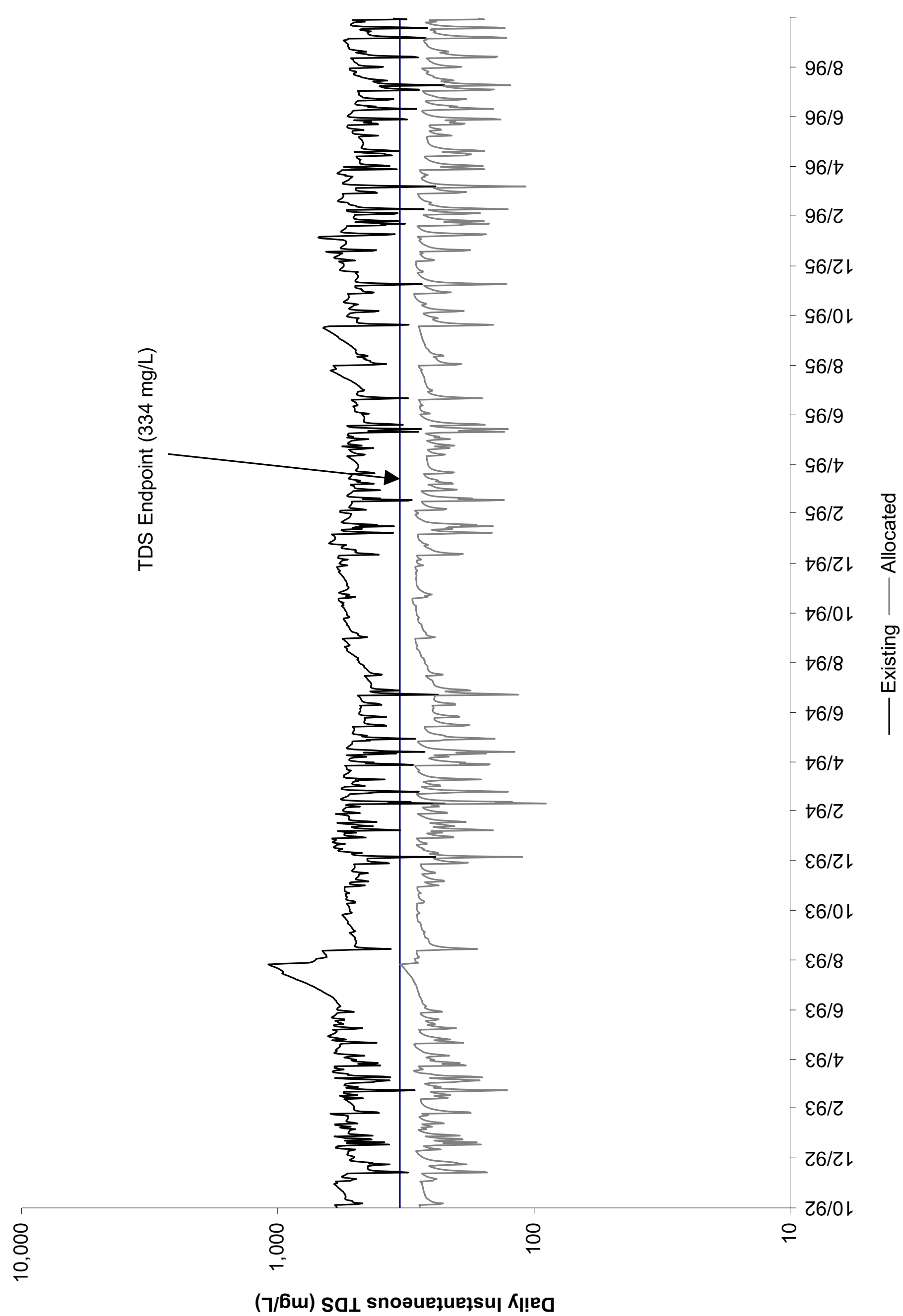

Figure 10.1 TDS concentrations for the Straight Creek impairment under existing and allocated conditions at the outlet.

10.3 Sediment TMDL

Allowable sediment loads for Straight Creek were developed with the Middle Creek watershed as the reference watershed. The area of the Middle Creek watershed was increased by the ratio of the impaired watershed area to the reference watershed area. Land use areas for the Middle Creek watershed were increased while maintaining the original land use distribution.

To aid in the development of TMDL allocation scenarios, nonpoint source areas were grouped into agriculture, forest, urban, and current and previously mined land, categories. Sub-categories for agriculture, urban, and forest were also included to provide better definition of allocation within the broader groupings (Table 10.3).

Table 10.3 Comparison of categorized sediment loads for the impaired and reference watersheds.

Sediment Source	Straight Creek (Mg/yr)	Reference Watershed Middle Creek Area-Adjusted (Mg/yr)
Agriculture		
Cropland	375.2	2,245
Pasture/Hay	40.59	25.53
Forest		
Forest	2,207	669.1
Forest Disturbed	1,040	3,495
Urban		
Commercial Impervious	1.33	3.51
Commercial Pervious	0.61	2.22
Residential Impervious	1.58	0.89
Residential Pervious	28.25	3.98
Current and Previously Mined Land		
Abandoned Mine Lands	15,014	0
Reclaimed Mine Area-not permitted	0	951.3
Permitted Mining:		
Reclaimed Mine Area	0.39	0
Active Mine Area	49.72	0

The target TMDL load for Straight Creek is the average annual load from the area-adjusted Middle Creek watershed under existing conditions (Table 10.4). The sediment

TMDL for Straight Creek includes three components – WLA, LA, and a MOS. The WLA was calculated as the sum of all permitted point source discharges. The MOS was explicitly set to 10% to account for uncertainty in developing TMDLs. The LA was calculated as the target TMDL load minus the WLA load minus the MOS.

Table 10.4 TMDL Targets for the impaired watershed.

Impairment	WLA (Mg/yr)	LA (Mg/yr)	MOS	TMDL (Mg/yr)
Straight Creek	50.1	6,607.8	739.8	7,397.7

Review of the Lee County Comprehensive Plan (Lee County Planning Commission, 2003) indicated that land use is not expected to change significantly over the next 25 years. The Straight Creek watershed is highly rural and it is assumed that residential and commercial growth in the watershed will not have an impact on future sediment loads. However, increased mining operations could have an impact if sediment control ponds exceed the permitted 70mg/L.

The reductions required to meet the TMDLs were based on the conditions existing at the time of impairment (Table 10.5). The final overall sediment load reduction required for Straight Creek is 64.58%.

Table 10.5 Required reductions from the impaired watershed.

Load Summary	Straight Creek (Mg/yr)	Reductions Required (Mg/yr)	Reductions Required (% of existing load)
Sediment Loads	18,792	12,136	64.58
Straight Final TMDL Load	6,656		
Target Modeling Load	6,658		

The sediment allocation scenario for Straight Creek is presented in Table 10.6 broken down into nonpoint sources and point sources. The scenario requires sediment reductions of 65% from disturbed forest, 79% from AML, as well as 100% reduction from straight pipes (uncontrolled residential discharges).

Table 10.6 Final TMDL allocation scenario for the impaired watershed.

Sediment Source	Straight Existing Loads (Mg/yr)	Reduction (%)	Straight Allocated Loads (Mg/yr)
Abandoned Mine Lands	15,014	79.0	3153
Commercial Impervious	1.33	0	1.33
Commercial Pervious	0.61	0	0.61
Cropland	2,207	0	2207
Forest	1,040	0	1040
Forest Disturbed	375.2	65.0	131
Pasture/Hay	40.59	0	40.59
Residential Impervious	1.58	0	1.58
Residential Pervious	28.25	0	28.25
NPS loads	**18,709**	**64.70**	**6,604**
Permitted Mining:			
Reclaimed mine area	0.39	0	0.39
Active mine area	49.72	0	49.72
VAR102252	0.02	0	0.02
Straight Pipes	30.55	100	0.00
PS loads	**80.68**	**37.86**	**50.14**
Channel Erosion	2.24	0	2.24
Watershed Total Loads	**18,792**	**64.58**	**6,656**

PART IV: IMPLEMENTATION AND PUBLIC PARTICIPATION

This page intentionally left blank

11. IMPLEMENTATION

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria and benthic impairments in the Straight Creek Watershed. The second step is to develop a TMDL Implementation Plan (IP). The final step is to implement the TMDL IP, and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by the EPA and the State Water Control Board (SWCB), measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the IP. The process for developing an implementation plan has been described in the *Guidance Manual for Total Maximum Daily Load Implementation Plans,* published in July 2003 and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

VADCR and VADEQ will work closely with watershed stakeholders, interested state agencies, and support groups to develop an acceptable implementation plan that will result in meeting the water quality target. Since this TMDL consists of NPS load allocations originating from mining activities, DMME will share responsibilities with VADCR during implementation.

11.1 Staged Implementation

Implementation of BMPs in the watershed will occur in stages. The benefit of staged implementation is that it provides a mechanism for developing public support and for evaluating the efficacy of the TMDL in achieving the water quality standard.

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas, the most promising management practice to control bacteria and minimize streambank erosion is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers. Reduced trampling and soil shear on streambanks by livestock hooves has been shown to reduce bank erosion.

Additionally, in both urban and rural areas, reducing the human bacteria loading from uncontrolled discharges (straight pipes) and failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on proper sewage disposal systems, septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;

3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the following Stage I scenarios are targeted at controllable, anthropogenic bacteria sources.

11.1.1 Staged Implementation – Bacteria

The goal of the Stage I scenarios is to reduce the bacteria loadings from controllable sources, excluding wildlife. The Stage I scenarios were generated with the same model setup as was used for the TMDL allocation scenarios.

The Stage I water quality goal was to reduce the number of violations of the instantaneous standard in Straight Creek to approximately 10%. Table 11.1 contains sets of reductions in land-based and direct loads that are projected to achieve this goal, along with a projected percent of violation occurrence. The Stage I allocation for Straight Creek requires a 100% reduction in loads from uncontrolled residential discharges (straight pipes), and no reductions in direct in-stream loads from livestock, land-based loads from urban and agricultural sources, and wildlife loads (Table 11.1, scenario 2).

Table 11.1 Reduction percentages for the Stage I implementation in Straight Creek.

Scenario Number	Percent Reduction in Loading from Existing Condition						Percent Violations	
	Direct Wildlife	NPS Wildlife	Direct Livestock	NPS Pasture/ Livestock	NPS Residential/ Urban	Straight Pipes	GM >126 cfu/ 100mL	Single Sample >235 cfu/ 100mL
1	0	0	0	0	0	0	100.0	84.29
2[1]	0	0	0	0	0	100	0.0	2.19
3	0	0	90	50	50	100	0.0	1.44
4	0	0	100	100	100	100	0.0	0.82
5	10	0	100	99	99	100	0.0	0.82
6	0	10	100	99	99	100	0.0	0.55
7	0	32	100	99	99	100	0.0	0.0
8[2]	0	32	0	80	99	100	0.0	0.0

[1]Stage I implementation scenario.
[2]Final TMDL allocation.

Table 11.2 details the load reductions required for meeting the Stage I Implementation for Straight Creek.

Table 11.2 Source loads at the Straight Creek impairment outlet for Stage I implementation.

Source	**Total Annual** *E. coli* **Loading for Existing Run** (cfu/yr)	**Total Annual** *E. coli* **Loading for Allocation Run** (cfu/yr)	Percent Reduction
Land Based			
Abandoned Mine Land	3.11E+13	3.11E+13	0
Active Mining	6.07E+12	6.07E+12	0
Barren	5.64E+10	5.64E+10	0
Commercial	8.69E+11	8.69E+11	0
Cropland	2.32E+11	2.32E+11	0
Forest	2.24E+14	2.24E+14	0
Livestock Access	3.33E+11	3.33E+11	0
Pasture	7.57E+12	7.57E+12	0
Reclaimed	4.38E+13	4.38E+13	0
Residential	6.60E+13	6.60E+13	0
Roads	4.66E+12	4.66E+12	0
Water	0.00E+00	0.00E+00	0
Wetland	2.46E+11	2.46E+11	0
Direct			
Livestock	3.55E+10	3.55E+10	0
Wildlife	5.70E+12	5.70E+12	0
Straight Pipes	4.96E+14	0.00E+00	100

11.1.2 Staged Implementation – TDS and Sediment

It is anticipated that AML reclamation and streambank stabilization will be the initial targets of implementation. One way to accelerate reclamation of AML is through remining. As noted on the DMME website (DMME, 2004):

> *"DMME, The Nature Conservancy, Virginia Tech/Powell River Project, and the U. S. Office of Surface Mining combined resources to develop proposals for incentives that will promote economically viable, environmentally beneficial remining operations that reclaim AML sites. Initial meetings led to the development of a Remining Ad Hoc Work Group that includes representatives from industry, other governmental agencies, special interest groups, and citizens of Southwest Virginia. The Ad Hoc Group has identified existing incentives and continues to propose new ones".*

One of the most important existing incentives is the alternative effluent limitations assigned to remining operations with pre-existing pollutant discharges. These regulations (known as the Rahall Amendment) were the result of a 1987 revision to the Federal Clean Water Act (CWA). Alternate effluent discharge limits are allowed in coal mining areas with pre-existing effluent problems. Operators document effluent conditions prior to remining. Upon completion of the remining operation and prior to reclamation bond and permit release, the operator would need to demonstrate that the pollution load from the site is equal to or less than pre-mining pollution load. Because the remining revisions were promulgated after the original TMDL provisions of the CWA, pollution load allocations and implementation plans should be designed to preserve the incentives implicit in the Rahall Amendment. Potential remining site include all abandoned mine land (AML).

Streambank stabilization in conjunction with riparian buffers will be useful in addressing both the TDS and sediment issues. Streambank stabilization will allow the development of a riparian zone, and will also reduce sediment delivery from the eroding streambank. TDS is associated with sediment delivery to the stream and the resulting increase in sediment/water contact. Decreasing streambank erosion problems should consequently have a beneficial impact on TDS as well as sediment levels. Riparian buffers slow surface water movement, allowing sediment to settle out before reaching the stream. In addition, to the degree that surface runoff is allowed to infiltrate as a result of being detained in the riparian zone, fine particulate matter will be captured in the soil matrix before entering the stream.

Through the remining process in Straight Creek, combined with streambank stabilization and development of riparian buffers, there exists reasonable assurance that the pollution load reductions proposed in the TMDL can be achieved. Some of the best supporting data on pollution load reductions resulting from successful remining operations are included with the EPA's remining document.

In 1998, the Pennsylvania Department of Environmental Protection (PADEP) developed a remining database to determine the success of Pennsylvania's remining program. The database specifically quantifies the extent to which bituminous coal remining sites have reduced pollution loads from the pre-existing conditions. Evaluations of the data were made by comparing pre-mining and post-mining loads at individual discharges for several parameters. The results are included in a report, broken down by stressor or pollutant. The database includes water quality information from more than 200 remining sites. BMPs used at the remining sites were common to surface mining activities throughout the Appalachian region and included daylighting deep mines, regrading, revegetation, and alkaline soil addition. The BMPs did not include chemical treatment, constructed wetlands, or long term treatment mechanisms. The PADEP results document that load reductions on the order of 60 to 70% were measured for pollutants of interest. When the observed pollution reductions associated with the remining process are compared to the modeled load reductions needed to improve Straight Creek, the recommended reductions for the stream appear attainable.

Waste load allocations and pollution load reductions necessary for active mining operations to meet Total Maximum Daily Loads (TMDLs) in watersheds where benthic stressors have been identified as suspended and dissolved solids, may be achieved with sediment control measures and best management practices (BMPs) instead of altered effluent limitations on permitted point source discharges.

Virginia's Coal Surface Mining Reclamation Regulations (CSMRR) require active mining operations to use sediment control measures and BMPs to prevent additional contributions of solids to stream flow and to minimize erosion to the extent possible. The measures include practices carried out within and adjacent to the disturbed mining area and consist of the utilization of proper mining and reclamation methods and control practices, singly or in combination. These methods and practices include, but are not limited to:

1) Disturbing the smallest area at any one time during the mining operation through progressive backfilling, grading, and prompt revegetation;
2) Stabilizing the backfill material to promote a reduction in the rate and volume of runoff;
3) Diverting runoff away from disturbed areas;
4) Directing water and runoff with protected channels;
5) Using straw, mulches, vegetative filters, and other measures to reduce overland flow;
6) Reclaiming all lands disturbed by mining as contemporaneously as practicable.

In addition to the use of sediment control measures and BMPs within the disturbed mine area, CSMRR require coal mining haulroads to be designed and constructed to ensure environmental protection appropriate for their intended use. In a watershed where pollution load reductions for solids are necessary for active mining operations to meet an approved TMDL, haulroad design, construction, and maintenance shall be performed considerate of the TMDL. This may include, but not limited to:

1) Using non-toxic-forming substances in road surfacing;
2) Paving haulroads;
3) Increasing the size of haulroad sumps.

Reduction in the sedimentation and mineralization of runoff attendant to mined land erosion and strata exposure may be achieved with sediment control measures and BMPs. Operation and reclamation plans mandated by CSMRR can be designed and developed to incorporate a BMP approach for meeting waste load allocations and pollution load reductions included in a TMDL for stream segments and watersheds where benthic stressors have been identified as suspended and dissolved solids. In selecting particular

BMPs to meet TDS reduction requirements VADEQ and/or VADMME will develop a cost analysis for these pollutant reductions in accordance with the SWCB directive during the September 27, 2005 meeting. This approach will be implemented in Virginia in lieu of altered effluent limitations for permitted coal mine point source discharges.

11.2 Link to Ongoing Restoration Efforts

Implementation of this TMDL will be integrated into on-going water quality improvement efforts aimed at restoring water quality in Straight Creek and the Powell River basin. Several BMPs known to be effective in controlling bacteria have also been identified for implementation as part of this effort. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of a nonpoint source implementation strategy.

11.3 Reasonable Assurance for Implementation

11.3.1 Follow-up Monitoring - Bacteria

VADEQ will continue monitoring the Straight Creek watershed in accordance with its ambient watershed monitoring program to evaluate reductions in fecal bacteria counts and the effectiveness of TMDL implementation in attainment of water quality standards.

Monitoring station(s) on Straight Creek will continue to be monitored. Watershed monitoring stations are designed to provide complete, census-based coverage of every watershed in Virginia. Two of the major data users in the Commonwealth (VADEQ and VADCR) have indicated that this is an important function for ambient water quality monitoring.

Watershed stations are located at the mouth and within the watershed, based on a census siting scheme. The number of stations in the watershed is determined by the NPS priority ranking, thus focusing our resources on known problem areas. Watersheds are monitored on a rotating basis such that, in the 6-year assessment cycle, all 493 watersheds are monitored. These stations will be sampled at a frequency of once every other month for a two-year period on a 6-year rotating basis.

11.3.2 Follow-up Monitoring – Benthic

VADEQ will continue to monitor at the listing biological monitoring station, 6BSRA000.11, or an appropriate biological site at the mouth of Straight Creek, as implementation of corrective actions in the watershed occur to evaluate when the Stage I implementation goals are achieved. Monitoring after corrective actions occur allows the most effective use of monitoring resources in the regional office. VADEQ will use data from this monitoring station to evaluate improvements in the benthic community and the effectiveness of TMDL implementation in attainment of the General Standard. Should the benthic community recover prior to attainment of the TDS and TSS WLAs, VADEQ and DMME will propose to EPA and the SWCB that the TDS/TSS WLAs be amended to reflect new information.

11.3.3 Regulatory Framework

While Section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) directs the State Water Control Board to *"develop and implement a plan to achieve fully supporting status for impaired waters"* (Section 62.1-44.19.7). WQMIRA also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary, and the associated costs, benefits and environmental impacts of addressing the impairments. The EPA outlines the minimum elements of an approvable implementation plan in its 1999 *Guidance for Water Quality-Based Decisions: The TMDL Process*. The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans, and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by the regional and local offices of VADEQ, VADCR, and other cooperating agencies.

Once developed, VADEQ will take TMDL implementation plans to the SWCB for approval as the plan for implementing the pollutant allocations and reductions contained in the TMDLs. Also, VADEQ will request SWCB authorization to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP) in accordance with the CWA's Section 303(e). In response to a Memorandum of Understanding (MOU) between the EPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to the EPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

11.3.4 Stormwater Permits

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is the VPDES Permit Regulation (9 VAC 25-31-10 et seq.). Section 9 VAC 25-31-120 describes the requirements for stormwater discharges. Also, federal regulations state in 40 CFR §122.44(k) that National Pollutant Discharge Elimination System (NPDES) permit conditions may consist of *"Best management practices to control or abate the discharge of pollutants when:… (2) Numeric effluent limitations are infeasible…"*.

There are currently no MS4 permits in the Straight Creek watershed.

11.3.5 Implementation Funding Sources

Funding sources for implementations will be identified by VADCR and DMME and the stakeholders. According to DMME's website, "Over 71,000 acres of land in Virginia have been affected by coal mining. It is estimated that it would take approximately 55 years at the present rate of funding and reclamation construction to reclaim just the high priority Abandoned Mine Land (AML) sites" (DMME, 2005). In addition, it would cost more than $300 million to reclaim the AML sites causing environmental degradation. One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. In response to the federal Clean Water Action Plan, Virginia developed a Unified Watershed Assessment that identifies watershed priorities. Watershed restoration activities, such as TMDL implementation, within these priority watersheds are eligible for Section 319 funding. Increases in Section 319 funding in future years will be targeted towards TMDL implementation and watershed restoration. Additional funding sources may be available through the U. S. Office of Surface Mining.

11.3.6 Use Attainability Analysis

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use. In order for a stream to be assigned a new designated use, or a subcategory of a use, the current designated use must be removed. To remove a designated use, the state must demonstrate that the use is not an existing use, and that downstream uses are protected. Such uses will be attained by implementing effluent limits required under §301b and §306 of the Clean Water Act and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10 paragraph I).

The state must also demonstrate that attaining the designated use is not feasible because:

1. Naturally occurring pollutant concentration prevent the attainment of the use;
2. Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation requirements to enable uses to be met;
3. Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place;
4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate the modification in such a way that would result in the attainment of the use;
5. Physical conditions related to natural features of the water body, such as the lack of proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life use protection; or

6. Controls more stringent than those required by §301b and §306 of the Clean Water Act would result in substantial and widespread economic and social impact.

This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens as well as EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.virginia.gov/wqs/pdf/WQS05A_1.pdf.

11.3.7 Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that, even after removal of all bacteria sources other than wildlife, the stream will not attain standards under all flow regimes at all times. As is the case for Straight Creek, this stream may not be able to attain standards without some reduction in wildlife load. **Virginia and the EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards.**

Although previous TMDLs for the Commonwealth have not addressed wildlife reductions in first stage goals, some localities have already introduced wildlife management practices. While managing overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address this issue, Virginia proposed (during its recent triennial water quality standards review) a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the SWCB adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria were approved by the EPA and became effective in February 2004. Additional information can be found at http://www.deq.state.va.us/wqs/rule.html.

Based on the above, the EPA and Virginia have developed a process to address the wildlife issue. First in this process is the development of a Stage I scenario such as those presented previously in this chapter. The pollutant reductions in the Stage I scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of overpopulations. During the implementation of the Stage I scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in section 11.1 above. VADEQ will reassess water quality in the stream during and subsequent to the implementation of the Stage I scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedances attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

This page intentionally left blank

12. PUBLIC PARTICIPATION

The development of the Powell River TMDL greatly benefited from public involvement. Table 12.1 details the public participation throughout the project. The government kickoff meeting for Straight Creek took place on June 23, 2004 at the Municipal Building in Pennington Gap, Virginia with 18 people in attendance. The agencies represented at the meeting included VADCR, VADEQ, VDOF, DMME, TVA, and MapTech. The kickoff meeting was publicized through direct mailing to local agencies, government, and private companies.

The first public meeting for Straight Creek was held on August 11, 2004 at the Municipal Building in Pennington Gap, Virginia. Twenty-seven people (7 citizens, 8 agency, 3 local officials, 3 mining/coal industry representatives, 5 consultants, 1 news reporter) attended. To publicize the meeting, over 150 invitations and notices were sent out, newspapers and television stations were contacted, and agencies and localities were notified via email. In addition, DMME emailed their contact list of industries and agencies.

Table 12.1 Public participation during TMDL development for the Straight Creek watershed.

Date	Location	Attendance[1]	Type	Format
6/23/04	Municipal Building Pennington Gap, VA	18	Kickoff Meeting	Publicized to government agencies
8/11/04	Municipal Building Pennington Gap, VA	27	1st public	Open to public at large
2/10/2005	St. Charles Elementary School St. Charles, VA	97	Final public	Open to public at large

[1]The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to underestimate the actual attendance.

The draft TMDL document was available on the VADEQ website on February 8, 2005 for public review. The final public meeting was publicized by placing a notice in the Virginia Register February 7, 2005 issue. Notice of the meeting also ran in the legal section of the Kingsport Times on January 30, 2005. There were 255 notices of the meeting mailed to watershed landowners, agencies, Lee County locality staff, and other individuals that attended a previous meeting. Additional individuals were notified by email. Signs were placed on the road along Straight Creek and Stone Creek.

A total of 97 people attended the meeting. Agencies represented were MapTech, VADEQ, DMME, VADCR, TVA, DBSWCD, the Lee County Board, the Lee County Administrator, 2 news reporters (Powell Valley News and Kingsport Times), and the Lee County Litter Control officer. Sixteen attending lived in St. Charles. Over half of the audience worked for either Powell Mountain Coal or Lone Mountain Coal.

The 30-day public comment period was extended to April 13, 2005 in response to stakeholder requests for more time to review the TMDL and more information about the water quality model. Additionally, conference calls between DMME, VADEQ, MapTech, and coal industry representatives resulted in further opportunities for clarification and comment on technical issues beyond that provided at the public meetings. Comments were reviewed and replied to by DMME, VADEQ, and MapTech. The comments resulted in revisions to the Fecal Bacteria and General Standard TMDLs for Callahan Creek and Straight Creek of the Powell River Basin draft document. The revised TMDL document for Straight Creek was posted on the VADEQ website on July 11, 2005.

There was a 30-day public comment period between July 11, 2005 and August 11, 2005 for public comments on the changes made to the Straight Creek TMDL report. Comments were reviewed and replied to by DMME, VADEQ, and MapTech.

Public participation during the implementation plan (IP) development process will include the formation of stakeholders' committee and open public meetings. The stakeholders' committee will have the expressed purpose of formulating the TMDL IP. The committee may consist of, but not be limited to, representatives from the VADEQ, VADCR, VDH, local agricultural community, local urban community, coal company representatives, and local governments. This committee will have responsibility for identifying corrective actions that are founded in practicality, establish a time line to insure expeditious implementation, and set measurable goals and milestones for attaining water quality standards.

REFERENCES

American Veterinary Medical Association – Center for Information Management. 1997 U.S. Pet Ownership and Demographics Sourcebook.

Armour, C.L., D.A. Duff and W. Elmore. 1991. AFS Position Statement. Fisheries, Jan/Feb 1991, p. 7-11.

ASAE Standards, 45th Edition. 1998. D384.1 DEC93. Manure Production and Characteristics. St. Joseph, Mich.: ASAE.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, Benthic macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water, Washington, D.C.

Barfield, B.J., R.C. Warner, and C.T. Haan. 1983. Applied hydrology and sedimentology for disturbed lands. Second Printing. Oklahoma Technical Press. Stillwater, OK.

Bidrowski, T. 2003. Virginia Department of Game and Inland Fisheries. Personal telecommunication. January 29, 2003.

Bidrowski, T. 2004. Virginia Department of Game and Inland Fisheries. Personal telecommunication. July 16, 2004 and August 9, 2004.

BSE. 2003. Benthic TMDL for Stroubles Creek in Montgomery County, Virginia. Department of Biological Systems Engineering, Virginia Tech.

Chambers D.B. and Messinger T. 2001. Benthic Invertebrate Communities and their Responses to Selected Environmental Factors in the Kanawha River Basin, West Virginia, Virginia and North Carolina. United States Geological Survey. Charleston, WV.

Chow, V.T. 1959. Open Channel Hydraulics. McGraw-Hill Book Company. NY.

Clary, W.P. and B.F. Webster. 1989. Managing grazing of riparian areas in the Intermountain Region. USDA, Forest Service, Intermountain Research Station, General Technical Report INT-263, Ogden, UT.

Costanzo, G. 2003. Virginia Department of Game and Inland Fisheries. Personal telecommunication. January 29, 2003.

Cowan, W.L. 1956. Estimating hydraulic roughness coefficients. *Agricultural Engineering*, 37(7): 473-475.

DMME. 2005. Remining Incentives in Virginia. http://www.mme.state.va.us/Dmlr/Remining/Remining New Page2.htm

England, C.B. 1970. Land Capability: A Hydrologic Response Unit in Agricultural Watersheds. Agricultural Research Service, USDA, ARS: 41-172.

EPA. 1986. Quality Criteria For Water 1986. Washington DC.: USEPA Office of Water.

EPA. 1991. Guidance for Water-Quality-Based Decisions: The TMDL Process. EPAA440-4-91-001.

EPA. 1992. Multi-Resolution Land Cover (MRLC) Data for Virginia, a Component of the National Land Cover Dataset (NLCD). U.S. Environmental Protection Agency and the U.S. Geological Survey. Reston, VA.

EPA. 1998. Total Maximum Daily Load (TMDL) Program. Draft TMDL Program Implementation Strategy. February 12, 1998.

EPA. 1999. Guidance for Water Quality-Based Decisions: The TMDL Process. http://www.epa.gov/OWOW/tmdl/decisions/dec1c.html

EPA. 2000a. EPA BASINS Technical note6: Estimating hydrology and hydraulic parameters for HSPF. U.S. Environmental Protection Agency, Office of Water. Washington, D.C. EPA 823-R00-012. July 2000.

EPA. 2000b. Stressor Identification Guidance Document. U.S. Environmental Protection Agency, Office of Water. Washington, D.C. December 2000. EPA 822-B-00-025.

EPA. 2001. Coal Remining – Best Management Practices Guidance Manual. U.S. Environmental Protection Agency, Office of Water. Washington, D.C.

EPA. 2003. Total Maximum Daily Load (TMDL) Program and Individual Water Quality-Based Effluent Limitations. 40 CFR 130.7 (c)(1).

Evans, Barry M., Scott A. Sheeder, Kenneth J. Corradini, and Will w. Brown. 2001. AVGWLF version 3.2 Users Guide. Environmental Resources Research Institute, Pennsylvania State University and Pennsylvania Department of Environmental Protection, Bureau of Watershed Conservation.

Evans, B.M. 2002. Personal communications. August 6, 2003.

Farrar, R. 2003. Virginia Department of Game and Inland Fisheries. Personal telecommunication. January 15, 2003.

Fire Effects Information System. 1999. http://www.huntana.com/feis/animals/mammals.

Fies, M. 2004. Virginia Department of Game & Inland Fisheries. Personal telecommunication. August 11, 2004, August 12, 2004 and August 24, 2004.

Geldreich, E. E. 1978. Bacterial Populations and Indictor Concepts in Feces, Sewage, Stormwater, and Solid Wastes. In *Indicators of Viruses in Water and Food*, ed. G. Berg. Ann Arbor, Mich.: Ann Arbor Science Publishers, Inc.

Goodfellow, W.L., L.W. Ausley, D.T. Burton. D.L. Denton, P.B. Dorn, D.R. Grothe, M.A. Heber, T.J. Norberg-King and J.H. Rodges, Jr. 2000. Major Ion Toxicity in Effluents: A Review With Permitting Recommendations. Environmental Toxicology and Chemistry. 19(1): 175-182.

Haith, D.A. and L.L. Shoemaker, 1987. Generalized Watershed Loading Functions for Stream Flow Nutrients. Water Resources Bulletin, 23(3), pp. 471-478.

Haith, D.A., R. Mandel, and R.S. Wu. 1992. GWLF. Generalized Watershed Loading Functions, version 2.0 User's Manual. Department of Agricultural and Biological Engineering, Cornell University, Ithaca, New York.

Illinois Pollution Control Board (IPCB). Environmental regulations for the state of Illinois: Title 35 of the Illinois administrative code. Part 302.402. http://www.ipcb.state.il.us/Archive/dscgi/ds.py/Get/File-33354 Accessed: February 2, 2005.

Kaufman, J.B. and W.C. Krueger. 1984. Livestock impacts on riparian plant communities, and streamside management implications. A review. *Journal of Range Management* 37(3): 430-437.

Kennedy, A.J. 2002. An Ecotoxicological Assessment of a Treated Coal-mining Effluent in the Leading Creek Watershed, Meigs County, Ohio. MS thesis. Blacksburg, VA: Virginia Polytechnic Institute and State University. Department of Biology.

Kentucky Administrative Regulations Title 401: Chapter 5 Water Quality. p63. http://www.epa.gov/waterscience/standards/wqslibrary/ky/ky_4_wqs.pdf Accessed: February 2, 2005.

Klemm, D.J., K.A. Blocksom, W.T. Thoeny, F.A. Fulk, A.T. Herlihy, P.R. Kauffman and S.M. Cormier. 2001. Methods Development and Use of Macroinvertebrates as Indicators of Ecological Conditions For Streams In The Mid-Atlantic Highlands Region. Environmental Monitoring and Assessment. 78: 169-212.

Knox, M. 2003. Virginia Department of Game and Inland Fisheries. Personal telecommunication. January 15, 2003.

Knox, W. M. 2004. Virginia Department of Game & Inland Fisheries. Personal telecommunication. August 03, 2004, August 05, 2004, and August 25, 2004.

Lee County Planning Commission. 2003. Lee County Comprehensive Plan. County of Lee, Virginia.

Lloyd, K. 2004. Virginia Department of Environmental Quality. Personal telecommunication. September 28, 2004.

Li, E.A. 1975. A model to define hydrologic response units based on characteristics of the soil-vegetative complex within a drainage basin. M.S. Thesis, Department of Agricultural Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA.

MacDonald, D.D., C.G. Ingersoll, and T.A. Berger. 2000. Development and Evaluation of Consensus Based Sediment Quality Guidelines For Freshwater Ecosystems, Arch. *Environ. Contam. Toxicol.* 39: 20-31.

MapTech. 2002. Modeling Cattle Stream Access. Submitted to: VADCR, in cooperation with Biological Systems Engineering Department, Virginia Tech.

Merricks, T.C. 2003. *Evaluation of Hollow Fill Drainages and Associated Settling Ponds on Water Quality and Benthic Macroinvertebrate Communities in VA and WVA*. MS thesis. Blacksburg, VA: Virginia Polytechnic Institute and State University. Departments of Biology and Crop and Soil Environmental Science.

Metcalf and Eddy Inc. 1991. Wastewater Engineering. Treatment Disposal and Reuse. 3rd edition, McGraw-Hill Book Co., Singapore.

Mills, W.B., D.B. Porcella, M.J. Ungs, S.A. Gherini, K.V. Summers, L. Mok, G.L. Rupp, G.L. Bowie, and D.A. Haith. 1985. Water quality assessment: A screening procedure for toxic and conventional pollutants in surface and ground water. Part 1. EPA 600/6-85-002a. U. S. Environmental Protection Agency. Athens, Georgia.

Minitab, Inc. 1995. MINITAB Reference Manual Release 10 Xtra for Windows and Macintosh.

Mississippi Department of Environmental Quality (MDEQ):Office of Pollution Control. TMDL for Conductivity Long Branch, Pascagoula River Basin, Clark County, Ms. Proposed report: January, 2004.

New Jersey Department of Environmental Protection. State water quality standards. p42. http://www.state.nj.us/dep/wmm/sgwqt/2004swqs.pdf Accessed: February 2, 2005.

Norman, G.W. 2003. Virginia Department of Game and Inland Fisheries. Personal telecommunication.

Norman, G. 2004. Virginia Department of Game & Inland Fisheries. Personal telecommunication. July 12, 2004.

NRCS. 2004a. SSURGO website. http://www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/

NRCS. 2004b. STATSGO website. http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/

Ohio Environmental Protection Agency (OEPA). 2005. Water use designations and statewide criteria. p9. http://www.epa.state.oh.us/dsw/rules/01-07.pdf Accessed: February 2, 2005.

Pond, G. J. 2004. Effects of surface mining and residential land use on headwater stream biotic integrity. Kentucky Department of Environmental Protection Division of Water. July, 2004. p. 33.

Pond, G. J. 2005. USEPA. Personal telecommunication. January 10, 2005.

Reneau, R.B., Jr. 2000. Department of Crop and Soil Environmental Sciences, Virginia Tech. Personal communication. January 7, 2000.

Rose, R.K., Cranford, J.A. 1987. Handbook of Virginia Mammals. Final Report, Project No. 567460. VA Dept. Game & Inland Fisheries, Richmond, VA: 121.

SERCC. 2004. Southeast Regional Climate Center. http://water.dnr.state.sc.us/climate/sercc/

Soil Conservation Service. 1963. National Engineering Handbook. 3rd ed. Washington, D.C.: Government Printing Office.

SCS. 1986. Urban Hydrology for Small Watersheds, USDA Soil Conservation Service, Engineering Division, Technical Release 55.

Schwab, G. O., R. K. Frevert, T. W. Edminster, and K.K. Barnes. 1981. Soil and Water Conservation Engineering. 3rd ed. New York: John Wiley & Sons.

Society of Environmental Toxicology and Chemistry. 2004. Technical issue paper: Whole effluent toxicity testing: Ion imbalance. Pensacola Florida, USA: SETAC. 4p.

Soucek, D.J. 2001. Integrative Bioassessment of Acid Mine Drainage Impacts on the Upper Powell River Watershed, Southwestern VA. May 14, 2001: 62-63.

Stressor Identification Guidance Document. USEPA Office of Water. EPA-822-B-00-025. December 2000.

Tetra Tech, Inc. 2002. Total Maximum Daily Load (TMDL) development for Blacks Run and Cooks Creek. Prepared for EPA Region III, Virginia Department of Environmental Quality and Virginia Department of Conservation and Recreation. Available at //www.deq.virginia.gov/tmdl/apptmdls/shenrvr/cooksbd2.pdf

USCB. 1990. *1990 Census*. United States Census Bureau. Washington D.C.

USCB. 2000. *2000 Census*. United States Census Bureau. Washington D.C.

USDI, Bureau of Land Management. 1996. Riparian area management: process for assessing proper functioning conditions. Technical Reference 1737-9, National Applied Science Center, Denver, CO.

VADCR. 2002. Virginia 2002 NPS Assessment Land use/Land Cover Acreage. Virginia Department of Conservation and Recreation, Richmond, VA.

VADCR/DSWC. 1992. VirGIS Soils Database. Virginia Department of Conservation and Recreation, Richmond, VA.

VADCR and VADEQ. 2003. Guidance Manual for Total Maximum Daily Load Implementation Plans. http://www.deq.virginia.gov/tmdl/implans/ipguide.pdf.

VADEQ. 1997. Section 303(d) Total Maximum Daily Load Priority List.

VADEQ and VADCR. 1998. Section 303(d) Total Maximum Daily Load Priority List and Report (DRAFT).

VADEQ. 2002. Section 303(d) Report on Impaired Waters (DRAFT).

VADEQ. 2004. Section 303(d) Water Quality Assessment Integrated Report (DRAFT.).

VADEQ. 2005. Guidance Memo 05-2011. Accessible at: http://www.deq.state.va.us/waterguidance/pdf/052011.pdf.

VASS. 1995. Virginia Agricultural Statistics Bulletin 1994. Virginia Agricultural Statistic Service. Richmond, VA.

VASS. 2001. Virginia Agricultural Statistics Bulletin 2000. Virginia Agricultural Statistics Service. Richmond, VA.

VASS. 2002. Virginia Agricultural Statistics Bulletin 2001. Virginia Agricultural Statistics Service. Richmond, VA.

VASS. 2003. Virginia Agricultural Statistics Bulletin 2002. Virginia Agricultural Statistics Service. Richmond, VA.

VCE stats on percentage of time spent on pasture for dairy and beef cattle.

VDGIF. 1999. http://www.dgif.state.va.us. The Virginia Fish and Wildlife Information Service.

Virginia's State Water Control Board. 1997a. Water quality standard 9 VAC 25-260-20. General Standard.

Virginia's State Water Control Board. 1997b. Water quality standard 9 VAC 25-260-170. Fecal Coliform Standard.

Virginia's State Water Control Board. 2003. Water Quality Standards 9 VAC 25-260-5.

Voshell, J.R. 2002. A Guide To Common Freshwater Invertebrates of North America, 382. The McDonald & Woodward Publishing Company.

Weiskel. P.A., B.L. Howes, and G.R. Heufelder. 1996. Coliform contamination of a coastal embayment: sources and transport pathways. *Environ. Sci. Technol.* 30:1872-1881.

Wischmeier, W.H. and D.D. Smith. 1978. Predicting Rainfall Erosion Losses – A Guide to Conservation Planning. U.S. Department of Agriculture, Agriculture Handbook No. 537.

Wise County Planning Commission. 1998. Wise County Comprehensive Plan. County of Wise, Virginia.

Yagow, E. 1999. Unpublished monitoring data. Mountain Run TMDL Study.

Yagow, G., S. Mostaghimi, and T.A. Dillaha. 2002. GWLF model calibration for statewide NPS assessment. Virginia NPS pollutant load assessment methodology for 2002 and 2004 statewide NPS pollutant assessments. January 1 - March 31, 2002 Quarterly Report. Submitted to Virginia Department Conservation and Recreation, Division of Soil and Water Conservation, Richmond, Virginia.

This page intentionally left blank

GLOSSARY

Note: All entries in italics are taken from USEPA (1998).

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. *Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.*

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Antidegradation Policies. *Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

Aquatic ecosystem. *Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.*

Assimilative capacity. *The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.*

Background levels. *Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

Bacteria. *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial decomposition. *Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.*

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

Benthic. *Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.*

Benthic organisms. *Organisms living in, or on, bottom substrates in aquatic ecosystems.*

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Bioassessment. Evaluation of the condition of an ecosystem that uses biological surveys and other direct measurements of the resident biota. **(2)**

Biochemical Oxygen Demand (BOD). Represents the amount of oxygen consumed by bacteria as they break down organic matter in the water.

Biological Integrity. A water body's ability to support and maintain a balanced, integrated adaptive assemblage of organisms with species composition, diversity, and functional organization comparable to that of similar natural, or non-impacted habitat.

Biometric. (Biological Metric) The study of biological phenomena by measurements and statistics.

Biosolids. Biologically treated solids originating from municipal wastewater treatment plants.

Box and whisker plot. A graphical representation of the mean, lower quartile, upper quartile, upper limit, lower limit, and outliers of a data set.

Calibration. *The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.*

Cause. 1. That which produces an effect (a general definition).
2. A stressor or set of stressors that occur at an intensity, duration and frequency of exposure that results in a change in the ecological condition (a SI-specific definition). [2]

Channel. *A natural stream that conveys water; a ditch or channel excavated for the flow of water.*

Chloride. *An atom of chlorine in solution; an ion bearing a single negative charge.*

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.*

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Concentration-response model. A quantitative (usually statistical) model of the relationship between the concentration of a chemical to which a population or community of organisms is exposed and the frequency or magnitude of a biological response. (2)

Conductivity. An indirect measure of the presence of dissolved substances within water.

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Continuous discharge. *A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.*

Conventional pollutants. *As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.*

Conveyance. A measure of the of the water carrying capacity of a channel section. It is directly proportional to the discharge in the channel section.

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Cross-sectional area. *Wet area of a waterbody normal to the longitudinal component of the flow.*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Decay. *The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.*

Decomposition. *Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also* **Respiration.**

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge Monitoring Report (DMR). *Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.*

Discharge permits (under NPDES). *A permit issued by the EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

Dispersion. *The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics.*

Dissolved Oxygen (DO). The amount of oxygen in water. DO is a measure of the amount of oxygen available for biochemical activity in a waterbody.

Diurnal. *Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours. Also, the occurrence of an activity/process during the day rather than the night.*

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Dynamic model. *A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.*

Dynamic simulation. *Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time.*

Ecoregion. A region defined in part by its shared characteristics. These include meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

Ecosystem. *An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent guidelines. *The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

Enhancement. *In the context of restoration ecology, any improvement of a structural or functional attribute.*

Erosion. The detachment and transport of soil particles by water and wind. Sediment resulting from soil erosion represents the single largest source of nonpoint pollution in the United States.

Eutrophication. The process of enrichment of water bodies by nutrients. Waters receiving excessive nutrients may become eutrophic, are often undersirable for recreation, and may not support normal fish populations.

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Fate of pollutants*. Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.*

Fecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

Flux. *Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.*

General Standard. A narrative standard that ensures the general health of state waters. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life (9VAC25-260-20). (4)

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earths surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrograph*. A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

Hydrologic cycle. *The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

Hydrology. *The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

Impairment. A detrimental effect on the biological integrity of a water body that prevents attainment of the designated use.

IMPLND. An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

Indirect causation. The induction of effects through a series of cause-effect relationships, so that the impaired resource may not even be exposed to the initial cause.

Indirect effects. Changes in a resource that are due to a series of cause-effect relationships rather than to direct exposure to a contaminant or other stressor.

Infiltration capacity. *The capacity of a soil to allow water to infiltrate into or through it during a storm.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Interflow. Runoff that travels just below the surface of the soil.

Isolate. An inbreeding biological population that is isolated from similar populations by physical or other means.

Leachate. *Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills and can result in hazardous substances entering surface water, ground water, or soil.*

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

Margin of safety (MOS). *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by the EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mass balance. *An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.*

Mass loading. *The quantity of a pollutant transported to a waterbody.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

Metrics. Indices or parameters used to measure some aspect or characteristic of a water body's biological integrity. The metric changes in some predictable way with changes in water quality or habitat condition.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Mitigation. *Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace damaged ecosystems.*

Model. Mathematical representation of hydrologic and water quality processes. Effects of land use, slope, soil characteristics, and management practices are included.

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Mood's Median Test. A nonparametric (distribution-free) test used to test the equality of medians from two or more populations.

Narrative criteria*. Nonquantitative guidelines that describe the desired water quality goals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Nitrogen. An essential nutrient to the growth of organisms. Excessive amounts of nitrogen in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Nonpoint source. *Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

Numeric targets*. A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Numerical model. Model that approximates a solution of governing partial differential equations, which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.

Nutrient. An element or compound essential to life, including carbon, oxygen, nitrogen, phosphorus, and many others: as a pollutant, any element or compound, such as phosphorus or nitrogen, that in excessive amounts contributes to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Parameter. A numerical descriptive measure of a population. Since it is based on the observations of the population, its value is almost always unknown.

Peak runoff*. The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

PERLND. A pervious land segment in HSPF. It is used to model a particular land use segment within a subwatershed (e.g. pasture, urban land, or crop land).

Permit. *An authorization, license, or equivalent control document issued by the EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Permit Compliance System (PCS). *Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.*

Phased/staged approach. *Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Phosphorus. An essential nutrient to the growth of organisms. Excessive amounts of phosphorus in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Point source. *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

Pollution. *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

Postaudit. *A subsequent examination and verification of a model's predictive performance following implementation of an environmental control program.*

Privately owned treatment works. *Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period. *The time allowed for the public to express its views and concerns regarding action by the EPA or states (e.g., a* Federal Register *notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Quartile. The 25^{th}, 50^{th}, and 75^{th} percentiles of a data set. A percentile (p) of a data set ordered by magnitude is the value that has at most p% of the measurements in the data set below it, and (100-p)% above it. The 50^{th} quartile is also known as the median. The 25^{th} and 75^{th} quartiles are referred to as the lower and upper quartiles, respectively.

Rapid Bioassessment Protocol II (RBP II). A suite of measurements based on a quantitative assessment of benthic macroinvertebrates and a qualitative assessment of their habitat. RBP II scores are compared to a reference condition or conditions to determine to what degree a water body may be biologically impaired.

Reach. Segment of a stream or river.

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Reference Conditions. The chemical, physical, or biological quality or condition exhibited at either a single site or an aggregation of sites that are representative of non-impaired conditions for a watershed of a certain size, land use distribution, and other related characteristics. Reference conditions are used to describe reference sites.

Re-mining. Extracting resoures from land previously mined. This method is often used to reclaim abandoned mine areas.

Reserve capacity. *Pollutant loading rate set aside in determining stream waste load allocation, accounting for uncertainty and future growth.*

Residence time. *Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.*

Restoration. *Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone. *The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Roughness coefficient. *A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.*

Runoff. *That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

Seasonal Kendall test. A statistical tool used to test for trends in data, which is unaffected by seasonal cycles. (Gilbert, 1987)

Sediment. In the context of water quality, soil particles, sand, and minerals dislodged from the land and deposited into aquate systems as a result of erosion.

Septic system. *An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.*

Sewer. *A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

Simulation. *The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Source. An origination point, area, or entity that releases or emits a stressor. A source can alter the normal intensity, frequency, or duration of a natural attribute, whereby the attribute then becomes a stressor.

Spatial segmentation. *A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models.*

Staged Implementation. A process that allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard. As stream monitoring continues to occur, staged or phased implementation allows for water quality improvements to be recorded as they are being achieved. It also provides a measure of quality control, and it helps to ensure that the most cost-effective practices are implemented first.

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (e.g. 200 cfu/100 mL geometric mean limit).

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

Standard error. The standard deviation of a distribution of a sample statistic, esp. when the mean is used as the statistic.

Statistical significance. An indication that the differences being observed are not due to random error. The p-value indicates the probability that the differences are due to random error (i.e. a low p-value indicates statistical significance).

Steady-state model. *Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Model variables are treated as not changing with respect to time.*

Storm runoff. *Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream Reach. A straight portion of a stream.

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Stressor. Any physical, chemical, or biological entity that can induce an adverse response. [2]

Surface area. *The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water. *All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Suspended Solids. Usually fine sediments and organic matter. Suspended solids limit sunlight penetration into the water, inhibit oxygen uptake by fish, and alter aquatic habitat.

Technology-based standards. *Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.*

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (e.g. 15-minutes, 1-hour, 1-day).

Topography. *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Dissolved Solids (TDS). A measure of the concentration of dissolved inorganic chemicals in water.

Total Maximum Daily Load (TMDL). *The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.*

TMDL Implementation Plan. A document required by Virginia statute detailing the suite of pollution control measures needed to renediate an impaired stream segment. The plans are also required to include a schedule of actions, costs, and monitoring. Once implemented, the plan should result in the previously impaired water meeting water quality standards and achieving a "fully supporting" use support status.

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

TRC. Total Residual Chlorine. A measure of the effectiveness of chlorinating treated waste water effluent.

Tributary. *A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

Urban Runoff. Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model). *Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

DMLR. Virginia Department of mine Land Reclamation.

DMME. Virginia Department of Mines, Minerals, and Energy.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). *The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also Domestic wastewater.*

Wastewater treatment*. Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality*. The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality-based permit*. A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).*

Water quality criteria*. Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by the EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.*

Watershed. *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

WQIA. Water Quality Improvement Act.

This page intentionally left blank.

APPENDIX A

FREQUENCY ANALYSIS OF WATER QUALITY SAMPLING DATA

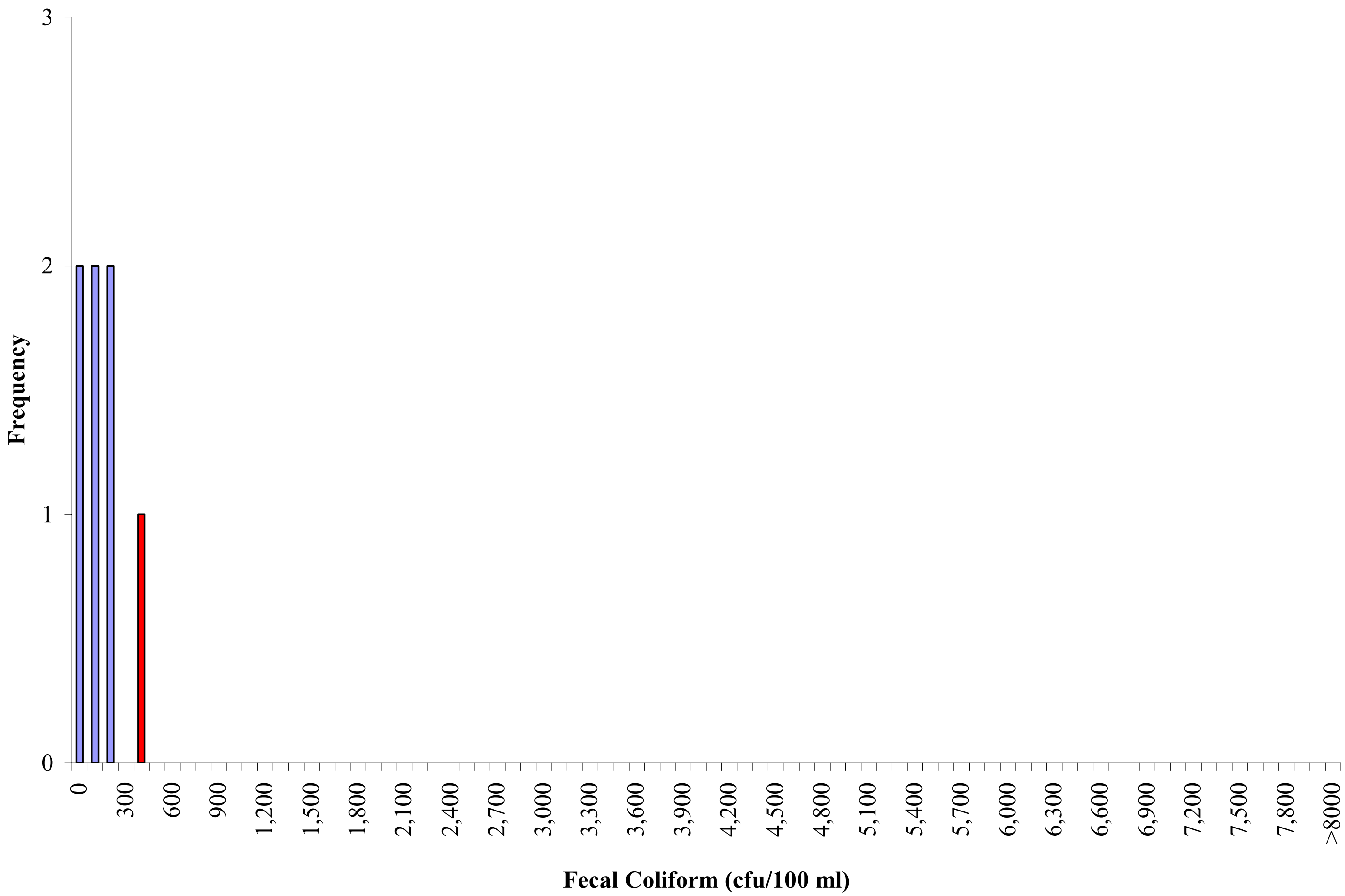

Figure A.1 Frequency analysis of fecal coliform concentrations at station 6BMIK000.07 in the Mud Lick impairment for period June 2002 to June 2003.
*Red indicates a value which violates the listing standard of 400 cfu/100 mL.

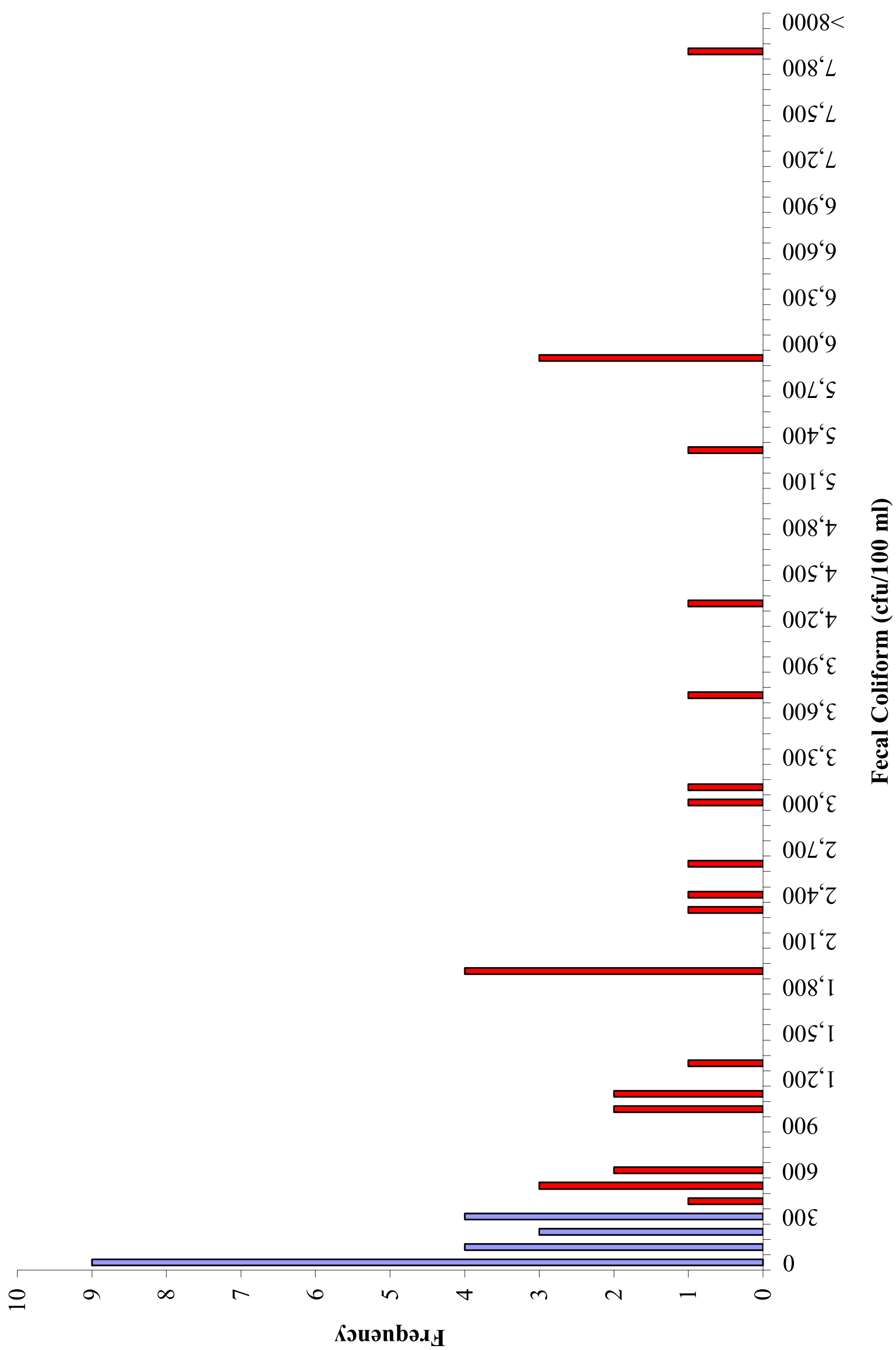

Figure A.2 Frequency analysis of fecal coliform concentrations at station 6BSRA001.11 in the Straight Creek impairment for period July 1990 to March 2001.
Red indicates a value which violates the listing standard of 400 cfu/100 mL.

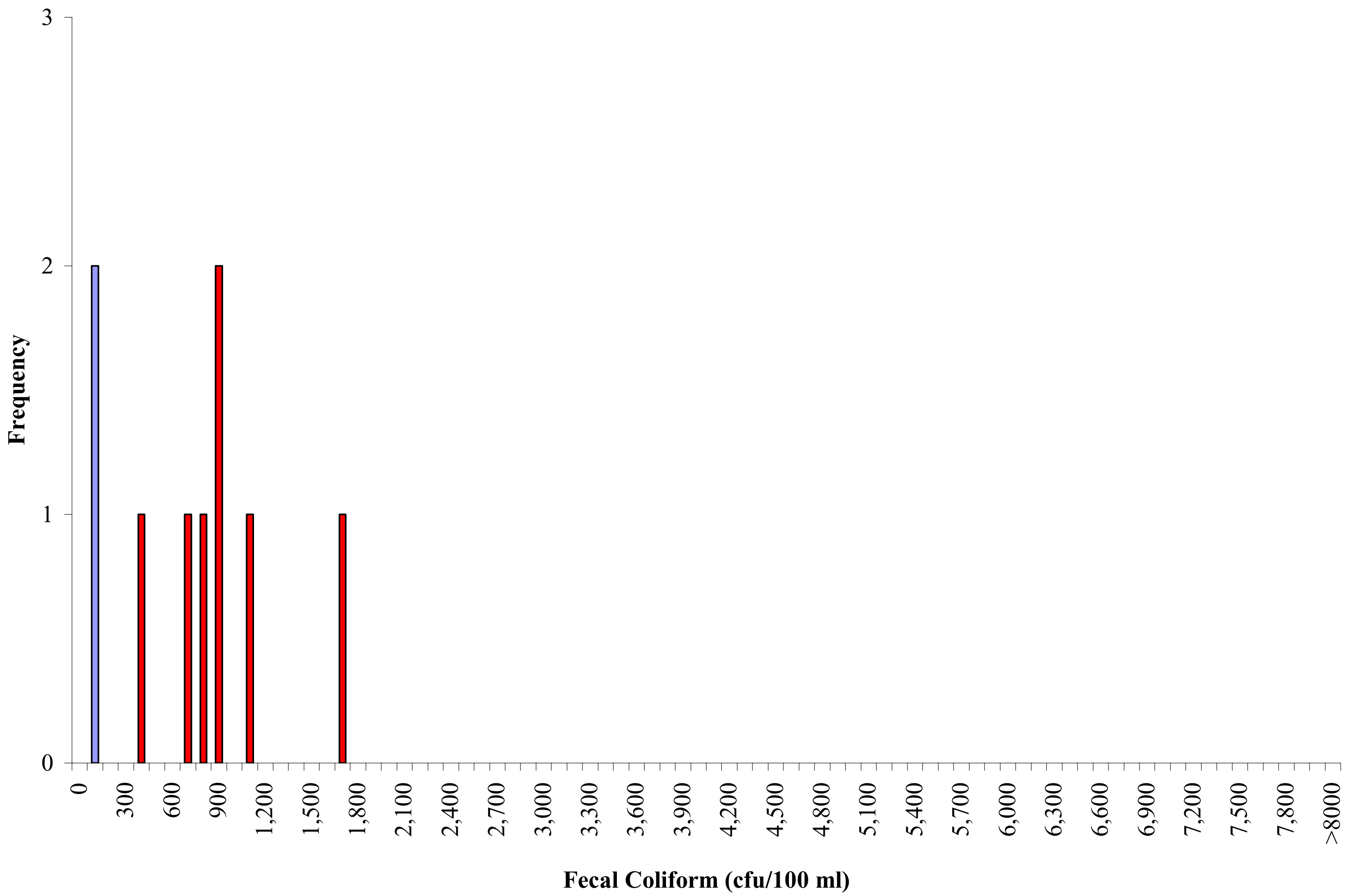

Figure A.3 Frequency analysis of fecal coliform concentrations at station 6BSRA003.22 in the Straight Creek impairment for period July 2003 to March 2004.
Red indicates a value which violates the listing standard of 400 cfu/100 mL.

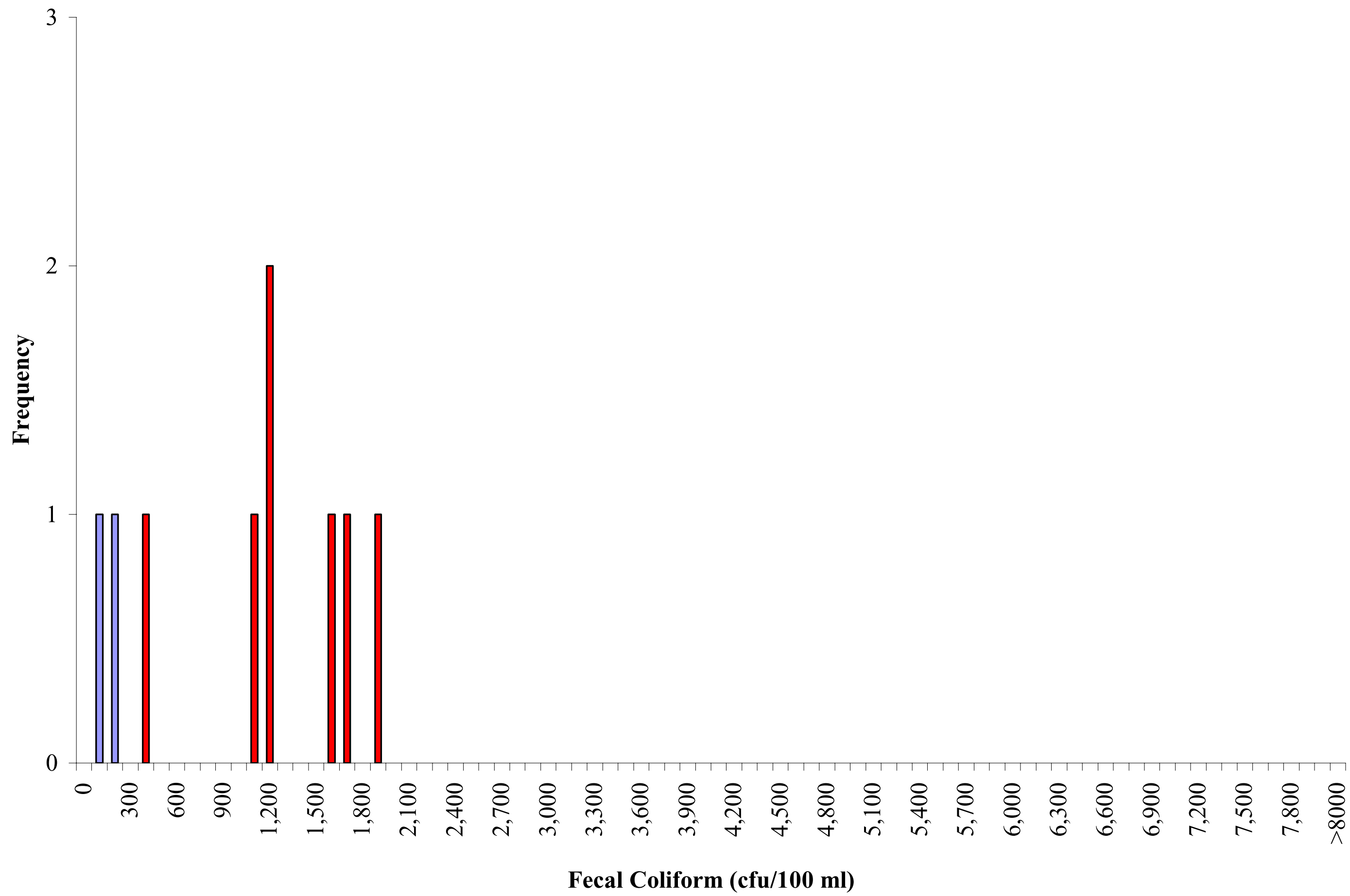

Figure A.4 Frequency analysis of fecal coliform concentrations at station 6BSRA004.16 in the Straight Creek impairment for period July 2003 to March 2004.
Red indicates a value which violates the listing standard of 400 cfu/100 mL.

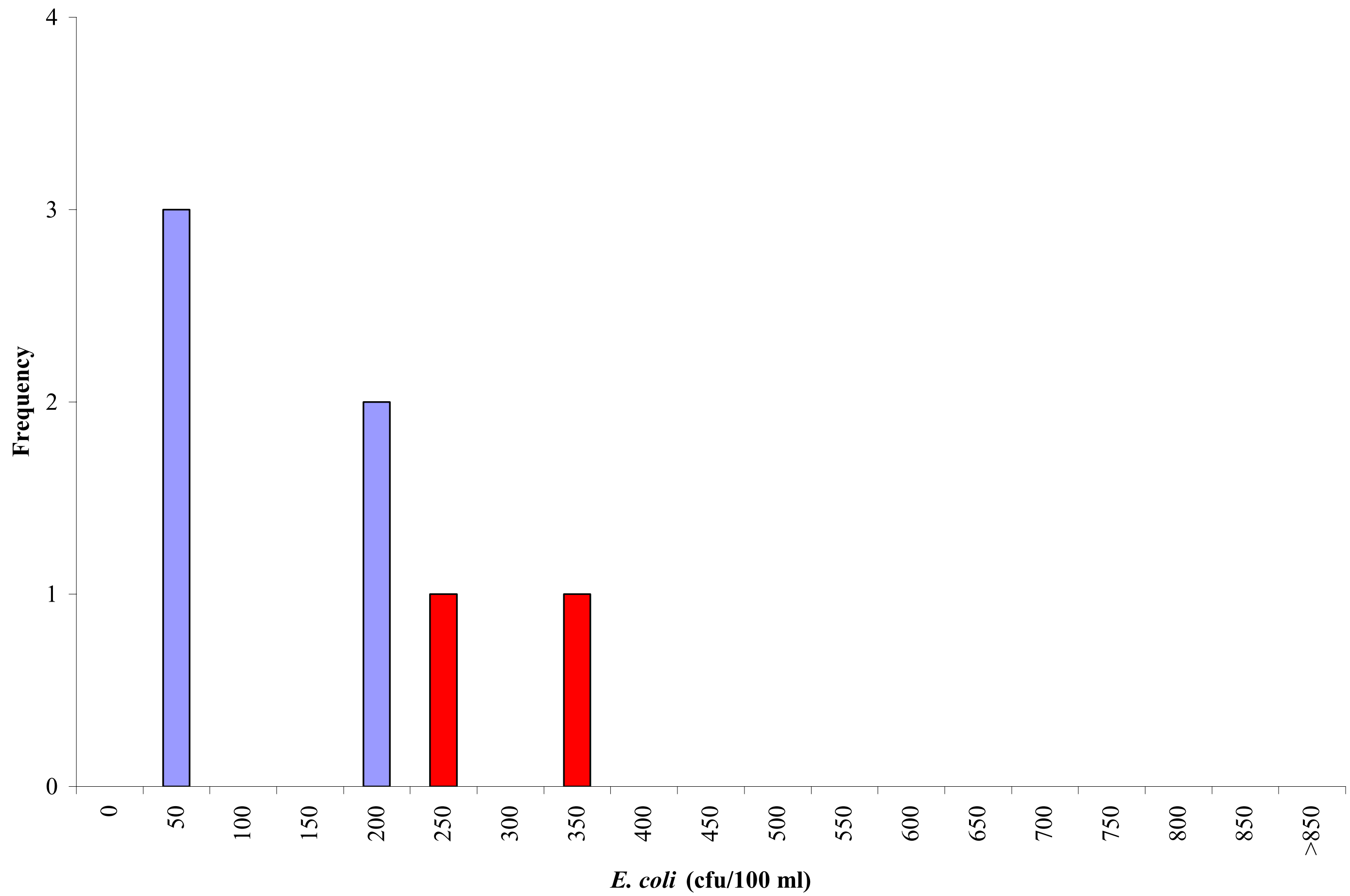

Figure A.5 Frequency analysis of *E. coli* concentrations at station 6BMIK000.07 in the Mud Lick impairment for period June 2002 to June 2003.
*Red indicates a value which violates the listing standard of 235 cfu/100 mL.

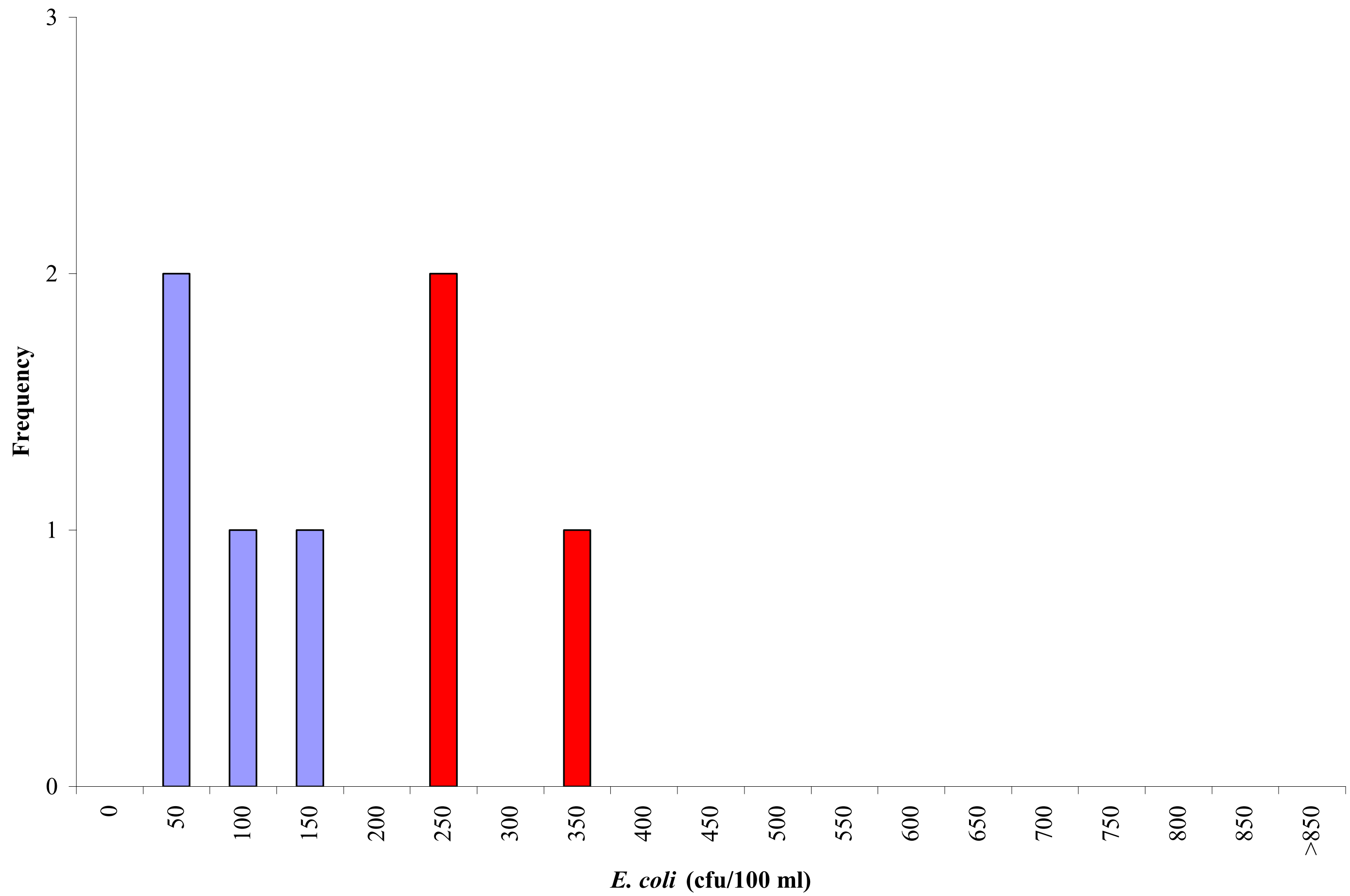

Figure A.6 Frequency analysis of *E. coli* concentrations at station 6BPIG000.04 in the Pigeon Creek impairment for period June 2002 to June 2003.
*Red indicates a value which violates the listing standard of 235 cfu/100 mL.

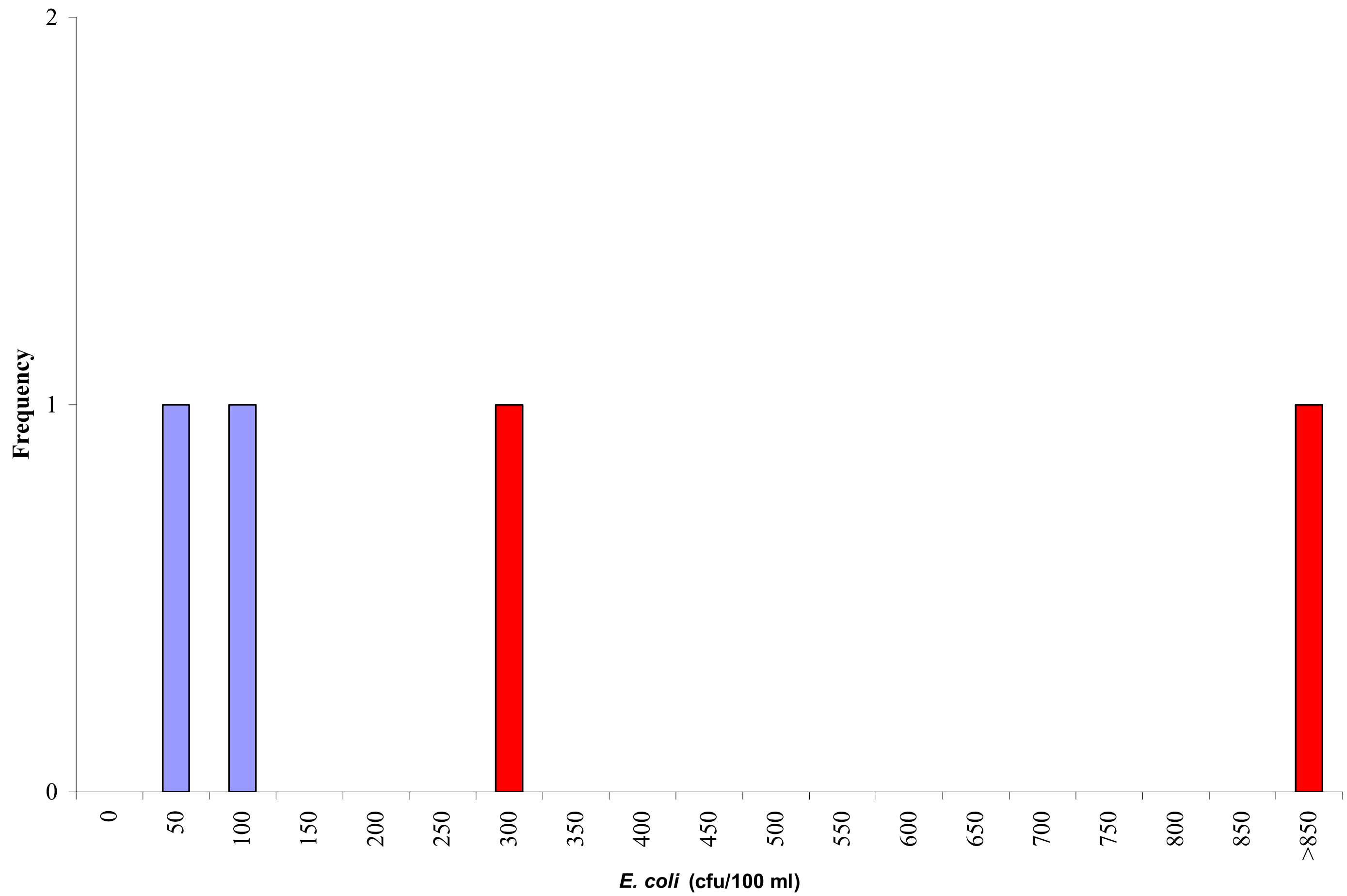

Figure A.7 Frequency analysis of *E. coli* concentrations at station 6BSRA000.10 in the Straight Creek impairment for period August 2003 to February 2004.
*Red indicates a value which violates the listing standard of 235 cfu/100 mL.

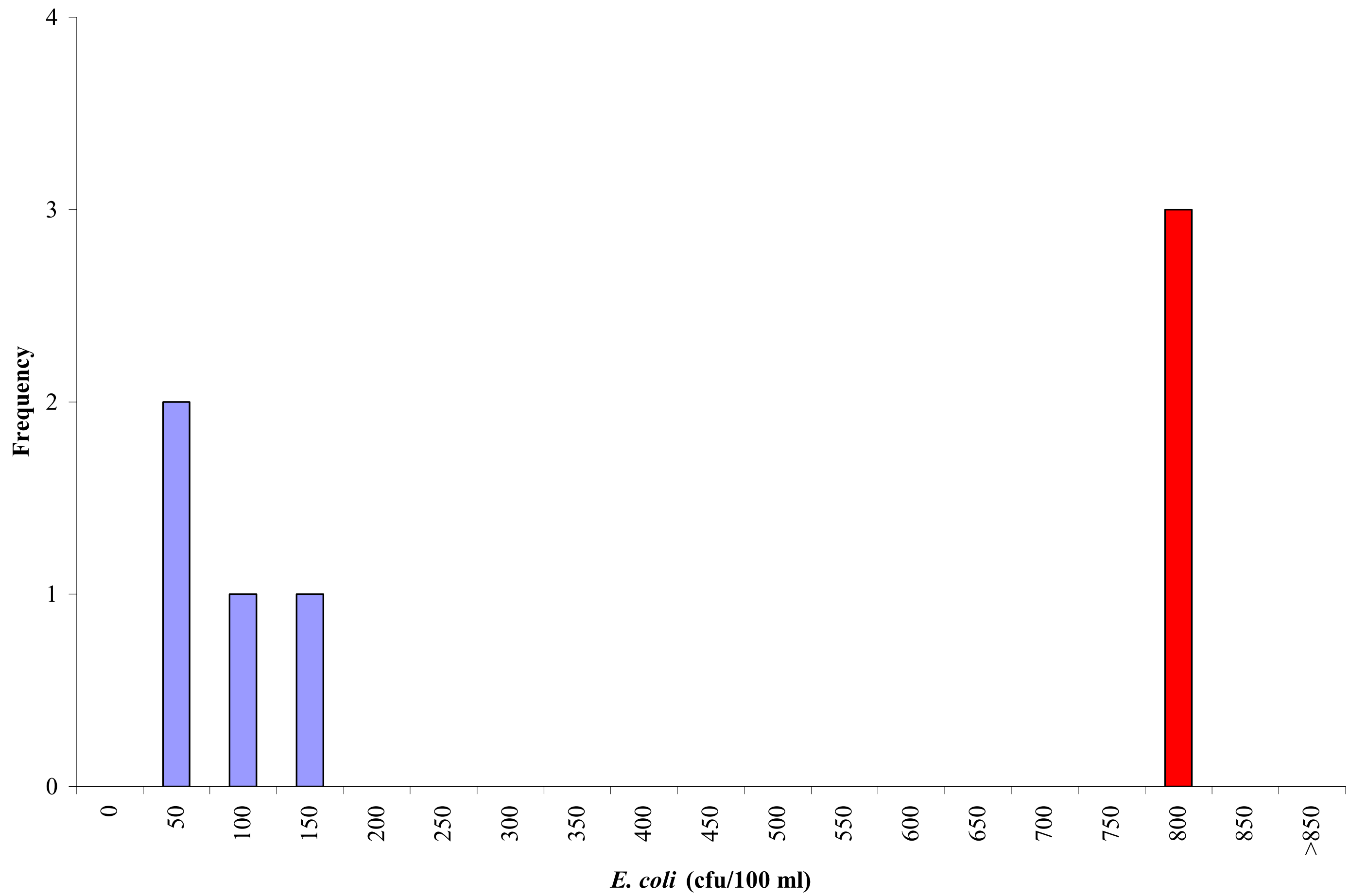

Figure A.8 Frequency analysis of *E. coli* concentrations at station 6BSRA001.11 in the Straight Creek impairment for period March 2000 to March 2001.

*Red indicates a value which violates the listing standard of 235 cfu/100 mL.

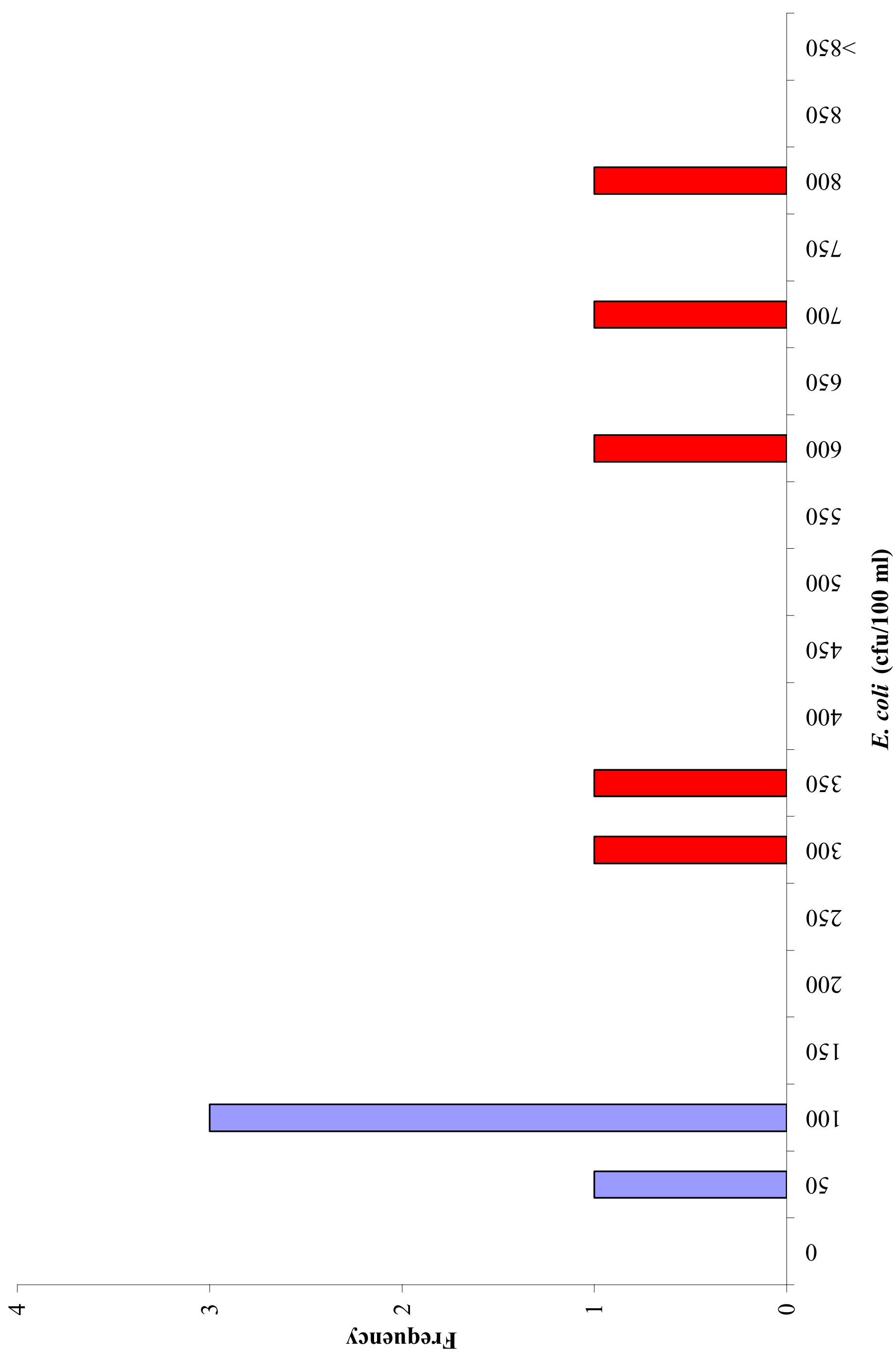

Figure A.9 Frequency analysis of *E. coli* concentrations at station 6BSRA003.22 in the Straight Creek impairment for period July 2003 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 mL.

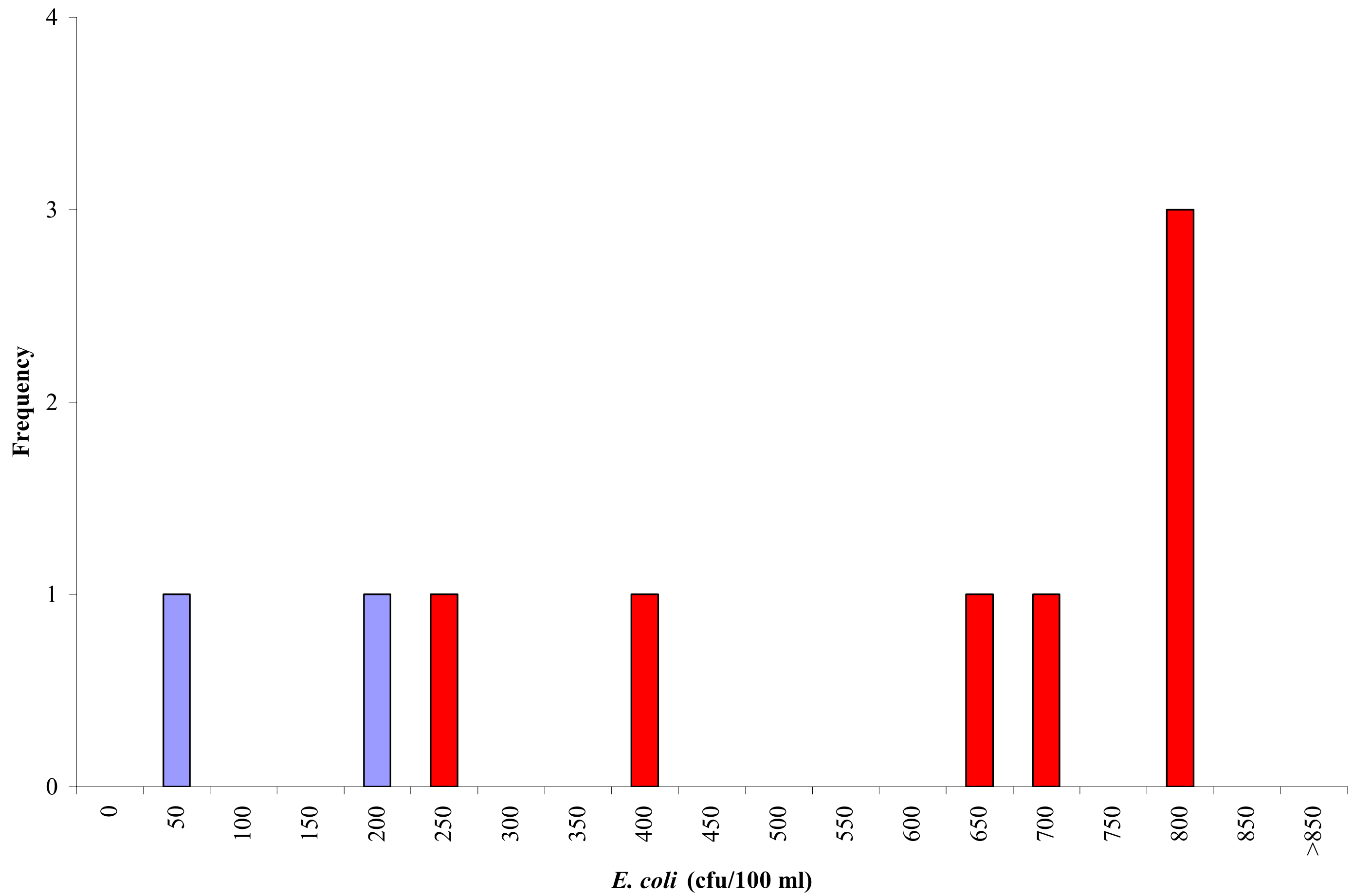

Figure A.10 Frequency analysis of *E. coli* concentrations at station 6BSRA004.16 in the Straight Creek impairment for period July 2003 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 mL

This page intentionally left blank

APPENDIX B

FECAL COLIFORM LOADS IN EXISTING CONDITIONS

Table B. 1 Current conditions of land applied fecal coliform load by land-use for the Straight Creek watershed (subwatersheds 6-9).

Land use	Active Mine (cfu)	Abandoned Mine Land (cfu)	Barren (cfu)	Commercial (cfu)	Cropland (cfu)	Forest (cfu)
January	5.16E+11	2.64E+12	4.79E+09	7.38E+10	1.97E+10	1.90E+13
February	4.66E+11	2.39E+12	4.32E+09	6.67E+10	1.78E+10	1.72E+13
March	5.16E+11	2.64E+12	4.79E+09	7.38E+10	1.97E+10	1.90E+13
April	4.99E+11	2.56E+12	4.63E+09	7.15E+10	1.90E+10	1.84E+13
May	5.16E+11	2.64E+12	4.79E+09	7.38E+10	1.97E+10	1.90E+13
June	4.99E+11	2.56E+12	4.63E+09	7.15E+10	1.90E+10	1.84E+13
July	5.16E+11	2.64E+12	4.79E+09	7.38E+10	1.97E+10	1.90E+13
August	5.16E+11	2.64E+12	4.79E+09	7.38E+10	1.97E+10	1.90E+13
September	4.99E+11	2.56E+12	4.63E+09	7.15E+10	1.90E+10	1.84E+13
October	5.16E+11	2.64E+12	4.79E+09	7.38E+10	1.97E+10	1.90E+13
November	4.99E+11	2.56E+12	4.63E+09	7.15E+10	1.90E+10	1.84E+13
December	5.16E+11	2.64E+12	4.79E+09	7.38E+10	1.97E+10	1.90E+13
Annual Total Loads (cfu/yr)	6.07E+12	3.11E+13	5.64E+10	8.69E+11	2.32E+11	2.24E+14

Table B.1 Current conditions of land applied fecal coliform load by land-use for the Straight Creek watershed (subwatersheds 6-9), (cont.)

Land use	Livestock Access (cfu)	Pasture/Hay (cfu)	Reclaimed Mine Land (cfu)	Residential (cfu)	Roads (cfu)	Wetland (cfu)
January	1.81E+10	6.56E+11	3.72E+12	6.26E+12	3.96E+11	2.09E+10
February	1.64E+10	5.92E+11	3.36E+12	5.54E+12	3.57E+11	1.89E+10
March	2.43E+10	6.48E+11	3.72E+12	5.89E+12	3.96E+11	2.09E+10
April	3.11E+10	6.18E+11	3.60E+12	5.58E+12	3.83E+11	2.02E+10
May	3.22E+10	6.38E+11	3.72E+12	5.65E+12	3.96E+11	2.09E+10
June	3.71E+10	6.1E+11	3.60E+12	5.35E+12	3.83E+11	2.02E+10
July	3.83E+10	6.31E+11	3.72E+12	5.28E+12	3.96E+11	2.09E+10
August	3.83E+10	6.31E+11	3.72E+12	5.28E+12	3.96E+11	2.09E+10
September	3.11E+10	6.18E+11	3.60E+12	5.11E+12	3.83E+11	2.02E+10
October	2.43E+10	6.48E+11	3.72E+12	5.16E+12	3.96E+11	2.09E+10
November	2.35E+10	6.27E+11	3.60E+12	5.11E+12	3.83E+11	2.02E+10
December	1.81E+10	6.56E+11	3.72E+12	5.77E+12	3.96E+11	2.09E+10
Annual Total Loads (cfu/yr)	3.33E+11	7.57E+12	4.38E+13	6.60E+13	4.66E+12	2.46E+11

Table B. 2 Monthly, directly deposited fecal coliform loads in each reach of the Straight Creek watershed (subwatersheds 6-9).

Reach	Source	Jan (cfu)	Feb (cfu)	Mar (cfu)	Apr (cfu)	May (cfu)	Jun (cfu)
6	Human/Pet	9.72E+12	8.78E+12	9.72E+12	9.41E+12	9.72E+12	9.41E+12
	Livestock	1.98E+08	1.79E+08	2.64E+08	3.83E+08	3.95E+08	4.46E+08
	Wildlife	1.04E+11	9.38E+10	1.04E+11	1.01E+11	1.04E+11	1.01E+11
7	Human/Pet	6.79E+12	6.14E+12	6.79E+12	6.58E+12	6.79E+12	6.58E+12
	Livestock	9.30E+03	8.40E+03	1.24E+04	1.80E+04	1.86E+04	2.10E+04
	Wildlife	8.00E+10	7.23E+10	8.00E+10	7.75E+10	8.00E+10	7.75E+10
8	Human/Pet	1.72E+13	1.55E+13	1.72E+13	1.66E+13	1.72E+13	1.66E+13
	Livestock	3.95E+08	3.57E+08	5.27E+08	7.65E+08	7.91E+08	8.93E+08
	Wildlife	1.41E+11	1.27E+11	1.41E+11	1.36E+11	1.41E+11	1.36E+11
9	Human/Pet	8.41E+12	7.60E+12	8.41E+12	8.14E+12	8.41E+12	8.14E+12
	Livestock	1.21E+09	1.10E+09	1.62E+09	2.35E+09	2.43E+09	2.74E+09
	Wildlife	1.59E+11	1.44E+11	1.59E+11	1.54E+11	1.59E+11	1.54E+11

Table B.2 Monthly, directly deposited fecal coliform loads in each reach of the Straight Creek watershed (subwatersheds 6-9) (cont.).

Reach	Source	Jul (cfu)	Aug (cfu)	Sep (cfu)	Oct (cfu)	Nov (cfu)	Dec (cfu)
6	Human/Pet	9.72E+12	9.72E+12	9.41E+12	9.72E+12	9.41E+12	9.72E+12
	Livestock	4.61E+08	4.61E+08	3.83E+08	2.64E+08	2.55E+08	1.98E+08
	Wildlife	1.04E+11	1.04E+11	1.01E+11	1.04E+11	1.01E+11	1.04E+11
7	Human/Pet	6.79E+12	6.79E+12	6.58E+12	6.79E+12	6.58E+12	6.79E+12
	Livestock	2.17E+04	2.17E+04	1.80E+04	1.24E+04	1.20E+04	9.30E+03
	Wildlife	8.00E+10	8.00E+10	7.75E+10	8.00E+10	7.75E+10	8.00E+10
8	Human/Pet	1.72E+13	1.72E+13	1.66E+13	1.72E+13	1.66E+13	1.72E+13
	Livestock	9.23E+08	9.23E+08	7.65E+08	5.27E+08	5.10E+08	3.95E+08
	Wildlife	1.41E+11	1.41E+11	1.36E+11	1.41E+11	1.36E+11	1.41E+11
9	Human/Pet	8.41E+12	8.41E+12	8.14E+12	8.41E+12	8.14E+12	8.41E+12
	Livestock	2.83E+09	2.83E+09	2.35E+09	1.62E+09	1.57E+09	1.21E+09
	Wildlife	1.59E+11	1.59E+11	1.54E+11	1.59E+11	1.54E+11	1.59E+11

Table B.3 Existing annual loads from direct-deposition sources for the Straight Creek watershed (subwatersheds 6-9).

Source	Annual Total Loads (cfu)
Human	
Straight pipes	4.96E+14
Livestock	
Beef	1.17E+10
Horse	2.38E+10
Other Cattle	2.38E+06
Wildlife	
Beaver	7.65E+09
Deer	2.18E+10
Duck	6.16E+08
Goose	5.57E+11
Muskrat	4.81E+12
Raccoon	3.05E+11
Turkey	8.63E+06
Total	**5.02E+14**

Table B. 4 Existing annual loads from land-based sources for the Straight Creek watershed (subwatersheds 6-9).

Source	Abandoned Mine Land (cfu)	Active Mine (cfu)	Commercial (cfu)	Cropland (cfu)	Forest (cfu)	Pasture/Hay (cfu)	Livestock Access (cfu)
Human							
Septic failures	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pet							
Cat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dog	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rooster	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Duck	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Goose	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turkey	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock							
Beef	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.21E+12	7.00E+10
Horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.52E+12	2.15E+11
Other Cattle	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.51E+08	1.97E+07
Wildlife							
Beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Deer	5.18E+12	4.89E+11	0.00E+00	2.70E+10	3.74E+13	1.11E+11	2.52E+09
Duck	1.55E+09	3.56E+08	8.27E+07	1.34E+07	1.12E+10	4.46E+07	4.72E+06
Goose	2.13E+12	4.89E+11	1.14E+11	1.84E+10	1.53E+13	6.13E+10	6.48E+09
Muskrat	1.00E+13	2.30E+12	5.34E+11	8.66E+10	7.20E+13	2.88E+11	3.05E+10
Raccoon	1.38E+13	2.79E+12	2.22E+11	9.95E+10	9.93E+13	3.79E+11	8.75E+09
Turkey	2.06E+09	1.94E+08	0.00E+00	2.68E+06	1.49E+10	1.10E+07	2.50E+05
Total	3.11E+13	6.07E+12	8.70E+11	2.32E+11	2.24E+14	7.57E+12	3.33E+11

Table B.4 Existing annual loads from land-based sources for the Straight Creek watershed (subwatersheds 6-9) (cont.).

Source	Barren (cfu)	Reclaimed Mine Land (cfu)	Residential (cfu)	Roads (cfu)	Water (cfu)	Wetland (cfu)
Human						
Septic failures	0.00E+00	0.00E+00	2.69E+13	0.00E+00	0.00E+00	0.00E+00
Pet						
Cat	0.00E+00	0.00E+00	2.42E+07	0.00E+00	0.00E+00	0.00E+00
Dog	0.00E+00	0.00E+00	2.71E+13	0.00E+00	0.00E+00	0.00E+00
Rooster	0.00E+00	0.00E+00	1.01E+12	0.00E+00	0.00E+00	0.00E+00
Duck	0.00E+00	0.00E+00	1.74E+09	0.00E+00	0.00E+00	0.00E+00
Goose	0.00E+00	0.00E+00	4.43E+12	0.00E+00	0.00E+00	0.00E+00
Turkey	0.00E+00	0.00E+00	2.33E+09	0.00E+00	0.00E+00	0.00E+00
Livestock						
Beef	0.00E+00	3.88E+13	0.00E+00	0.00E+00	1.17E+10	0.00E+00
Horse	0.00E+00	4.76E+12	0.00E+00	0.00E+00	2.38E+10	0.00E+00
Other Cattle	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.38E+06	0.00E+00
Wildlife						
Beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.65E+09	0.00E+00
Deer	0.00E+00	4.49E+10	8.31E+10	2.94E+11	0.00E+00	1.13E+10
Duck	2.91E+06	1.27E+07	5.91E+08	3.94E+08	0.00E+00	2.26E+07
Goose	3.99E+09	1.75E+10	8.11E+11	5.41E+11	0.00E+00	3.11E+10
Muskrat	1.88E+10	8.23E+10	3.81E+12	2.54E+12	0.00E+00	1.46E+11
Raccoon	3.36E+10	1.17E+11	1.90E+12	1.28E+12	0.00E+00	5.71E+10
Turkey	0.00E+00	1.78E+07	0.00E+00	1.15E+08	0.00E+00	4.50E+06
Total	5.64E+10	4.38E+13	6.60E+13	4.66E+12	4.32E+10	2.46E+11

APPENDIX C

IN-STREAM WATER CHEMISTRY DATA

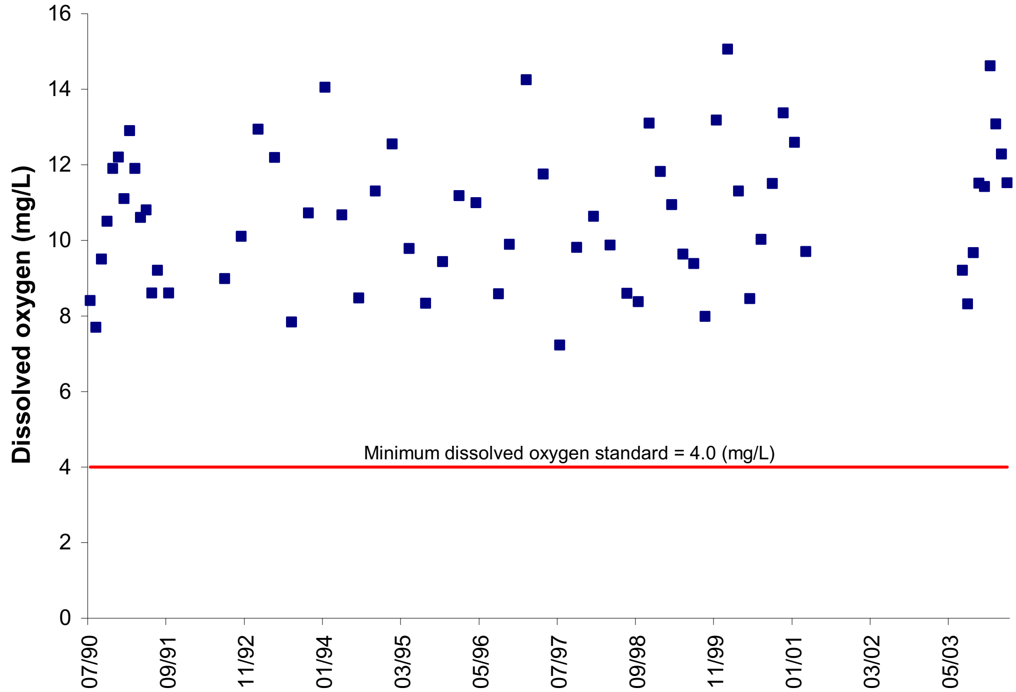

Figure C.1 Dissolved oxygen concentrations at VADEQ station 6BSRA001.11.

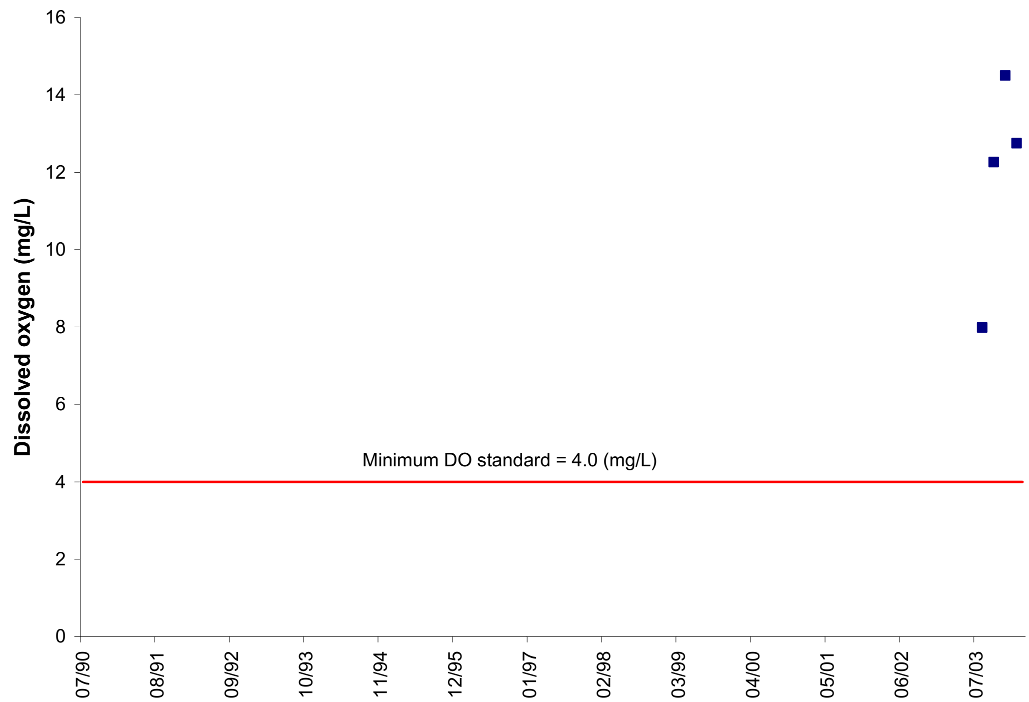

Figure C.2 Dissolved oxygen concentrations at VADEQ station 6BSRA000.10

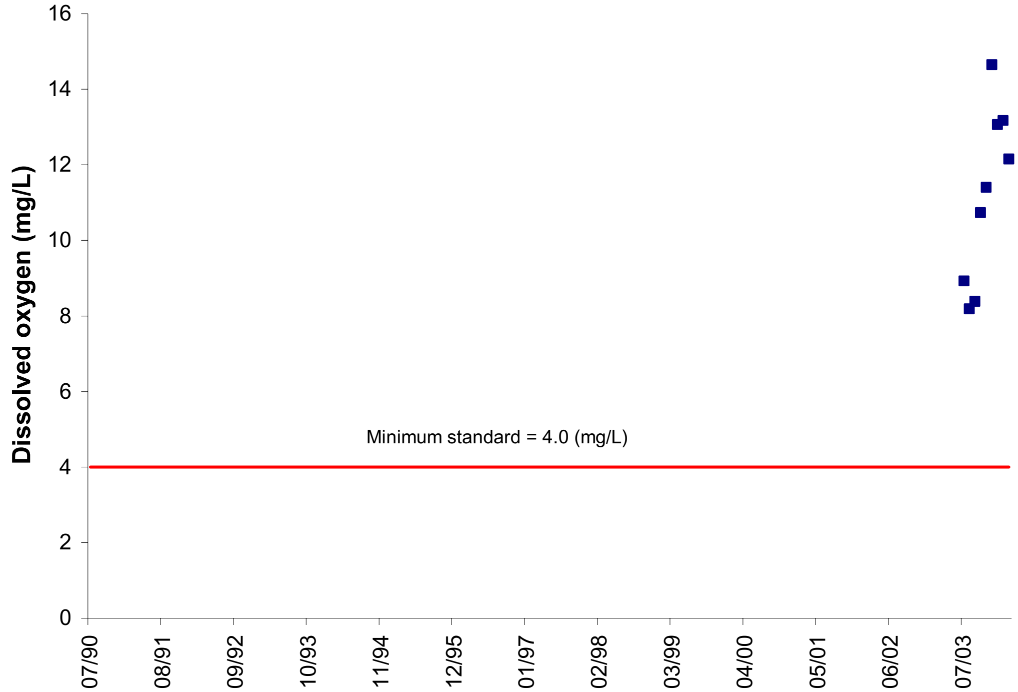

Figure C.3 Dissolved oxygen concentrations at VADEQ station 6BSRA003.22.

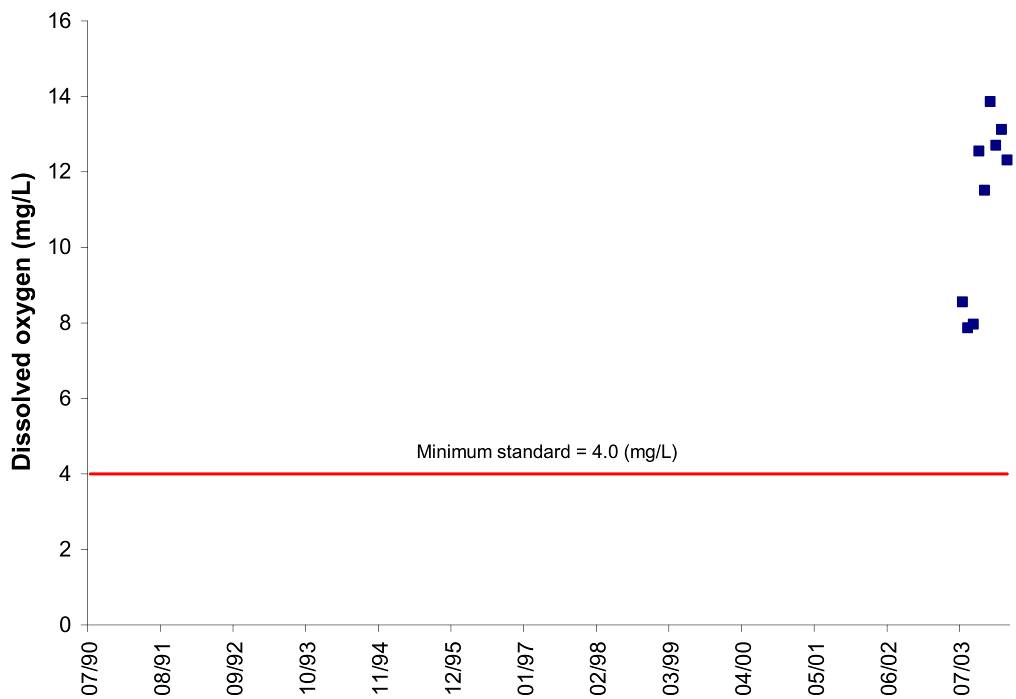

Figure C.4 Dissolved oxygen concentrations at VADEQ station 6BSRA004.16.

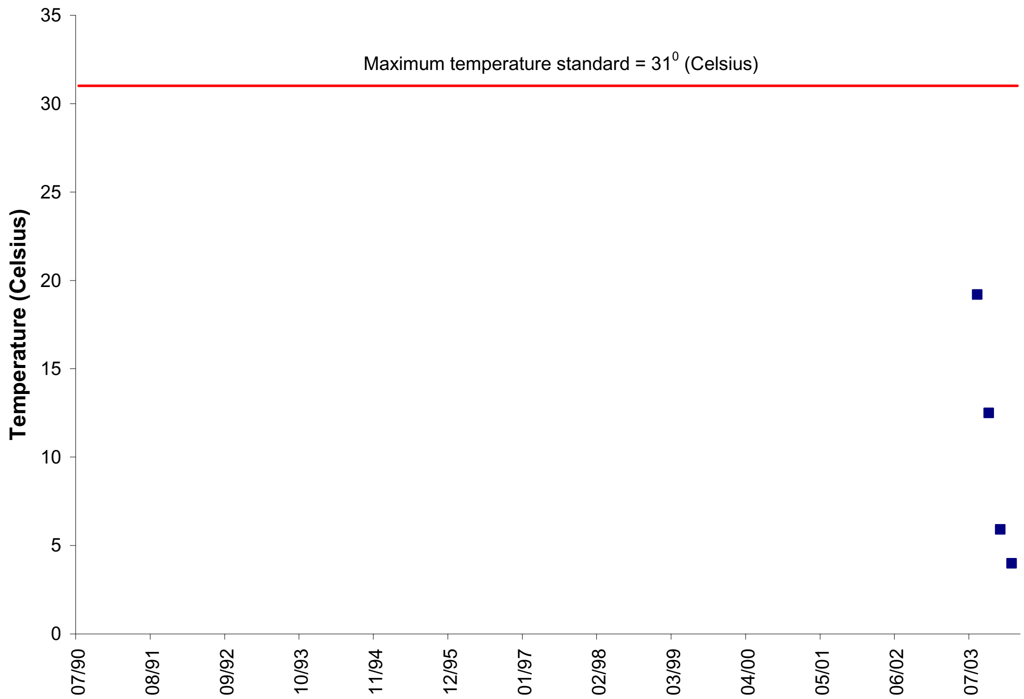

Figure C.5 Temperature values at VADEQ station 6BSRA000.10.

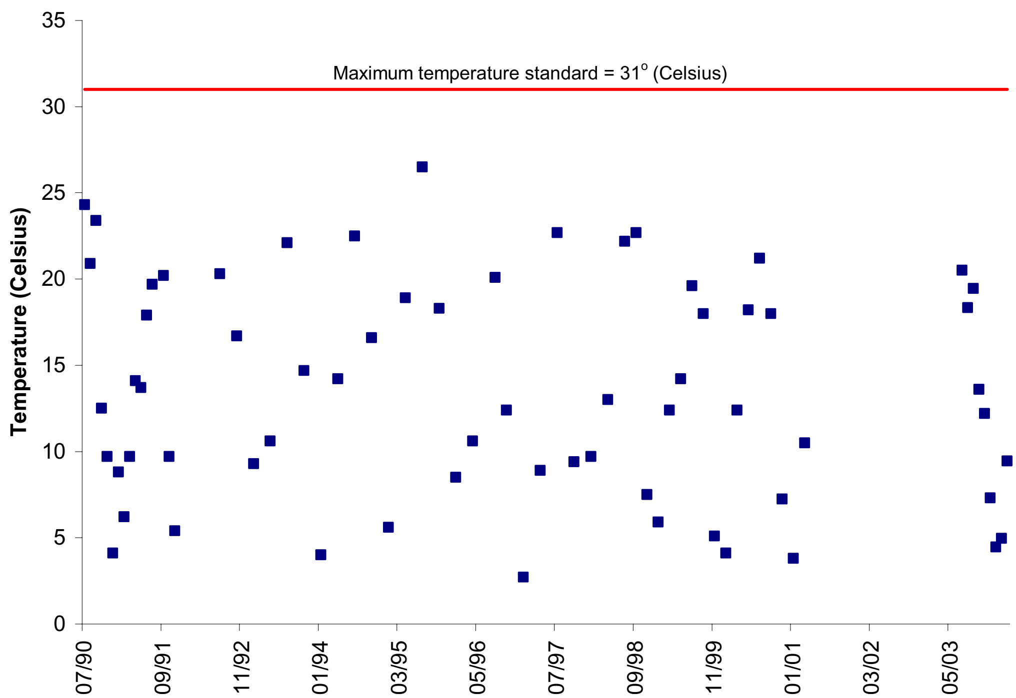

Figure C.6 Temperature values at VADEQ station 6BSRA001.11.

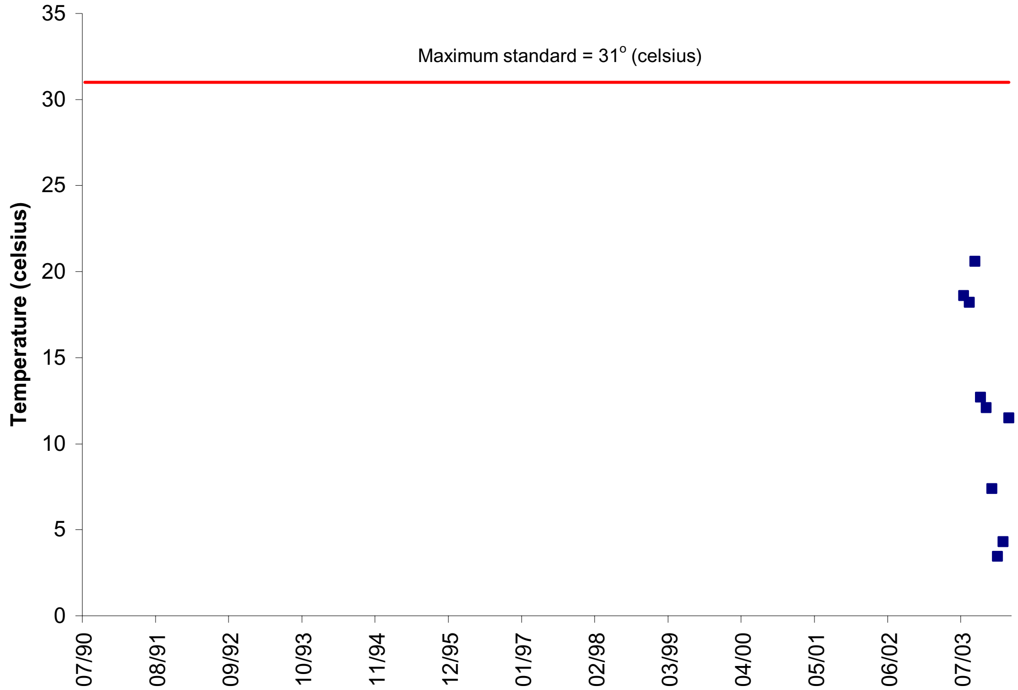

Figure C.7 Temperature values at VADEQ station 6BSRA003.22.

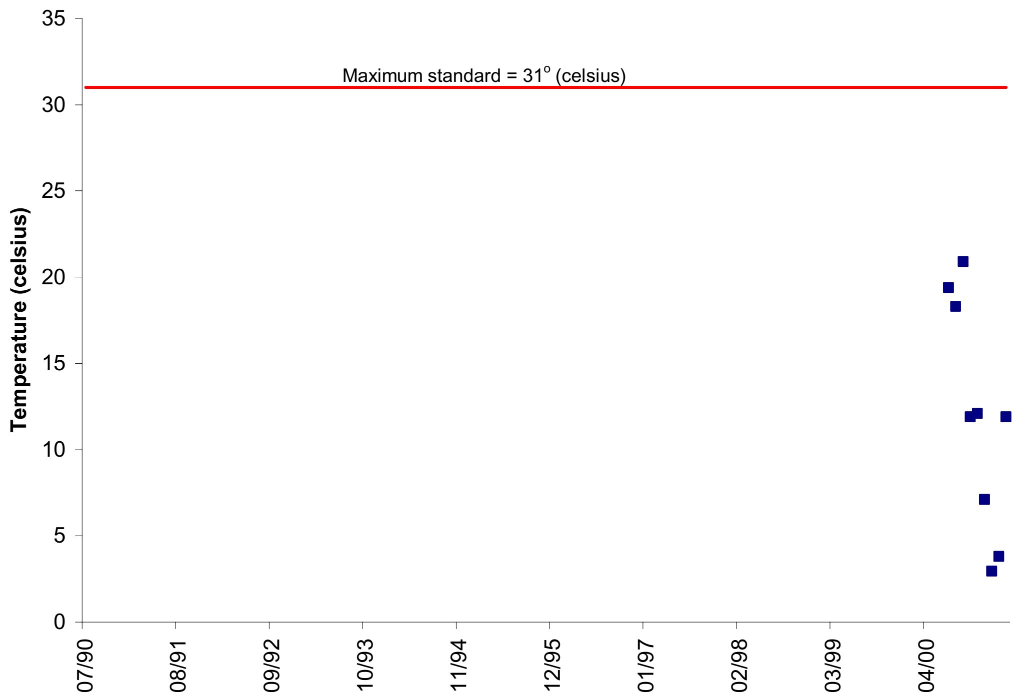

Figure C.8 Temperature values at VADEQ station 6BSRA004.16.

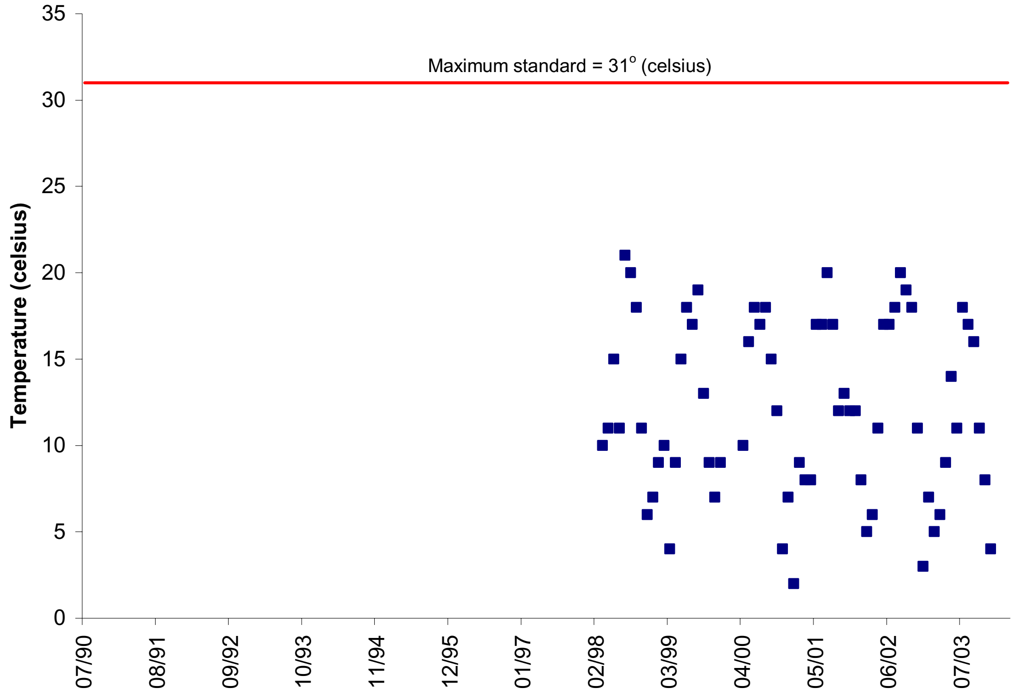

Figure C.9 Temperature values at DMME MPID 0002877.

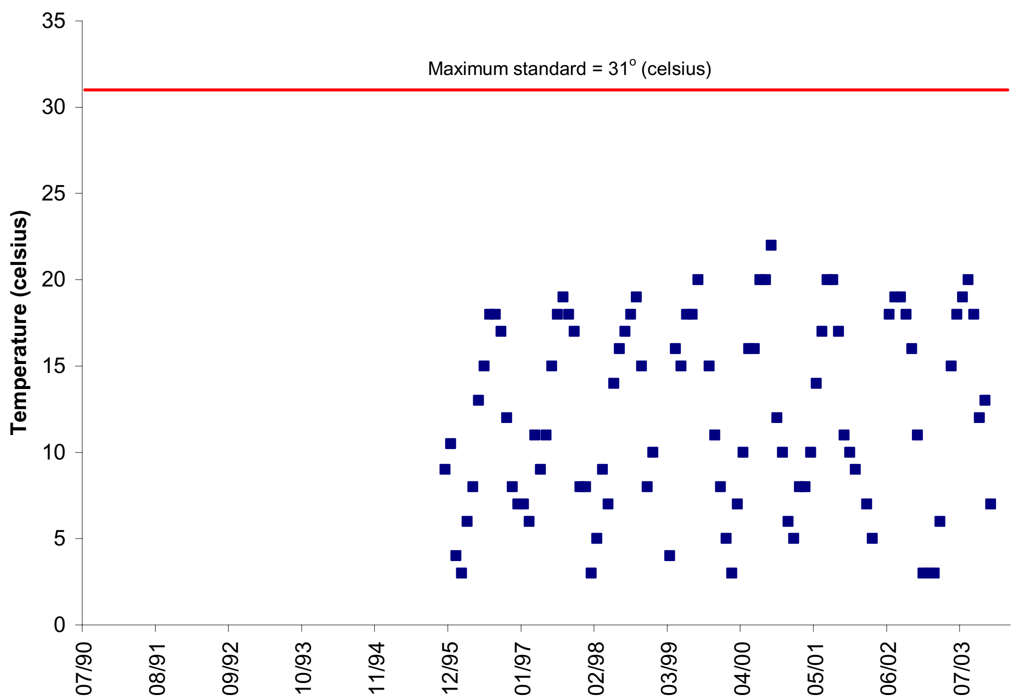

Figure C.10 Temperature values at DMME MPID 1020127.

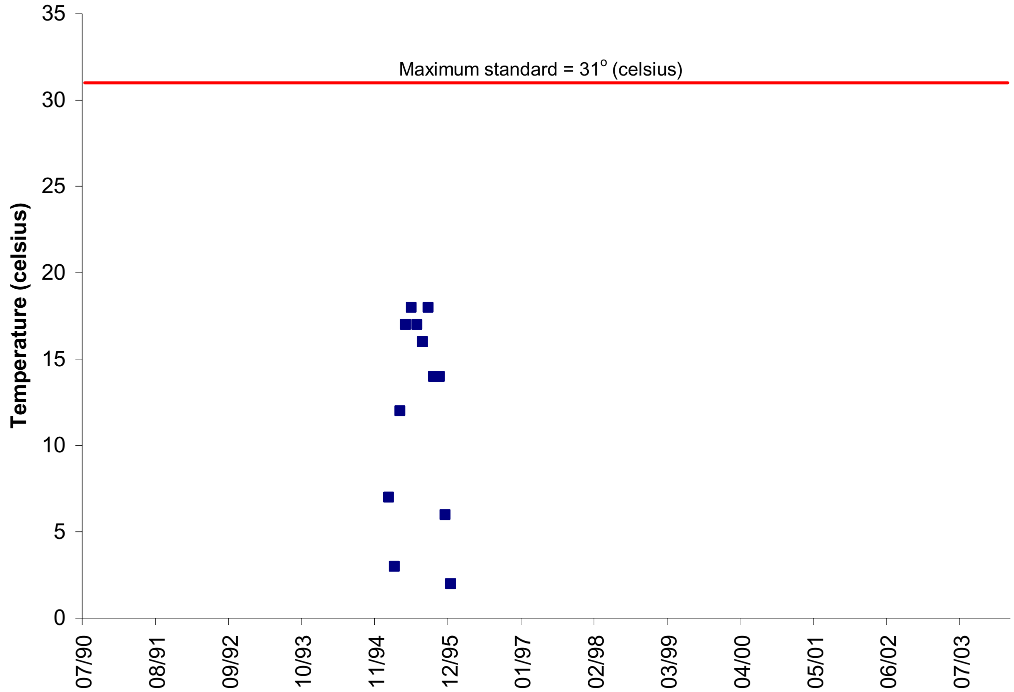

Figure C.11 Temperature values at DMME MPID 1020209.

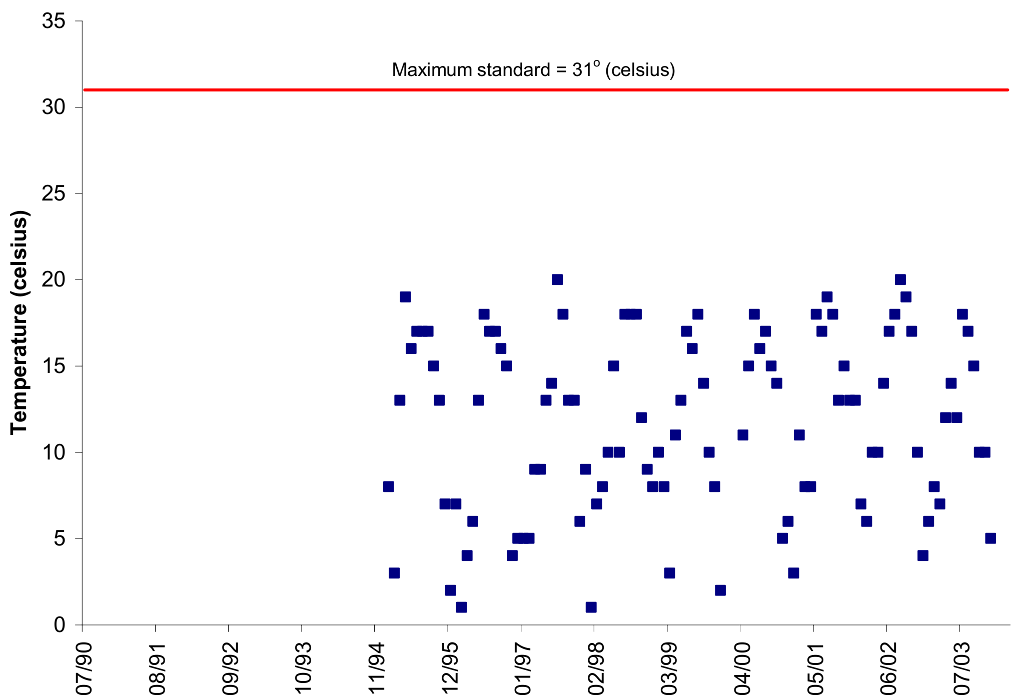

Figure C.12 Temperature values at DMME MPID 1020225.

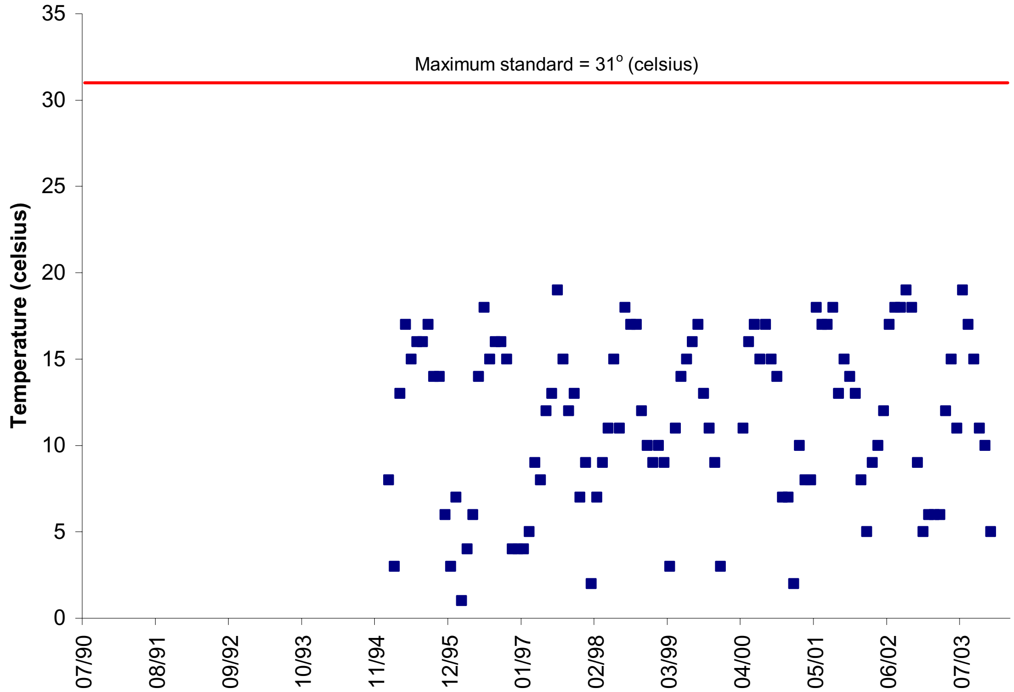

Figure C.13 Temperature values at DMME MPID 1020226.

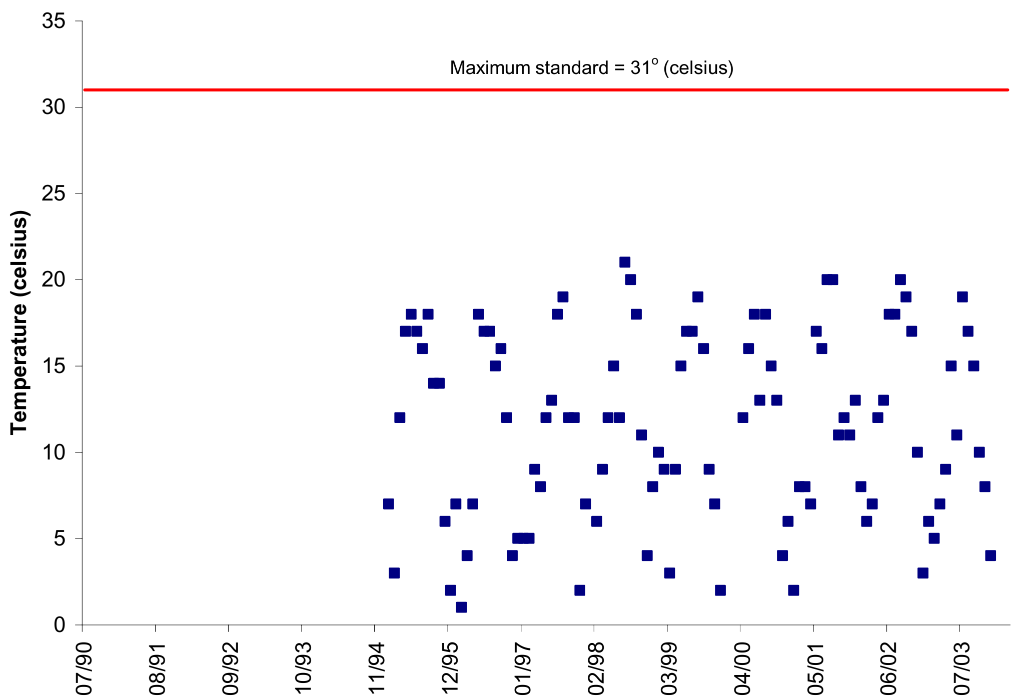

Figure C.14 Temperature values at DMME MPID 1020237.

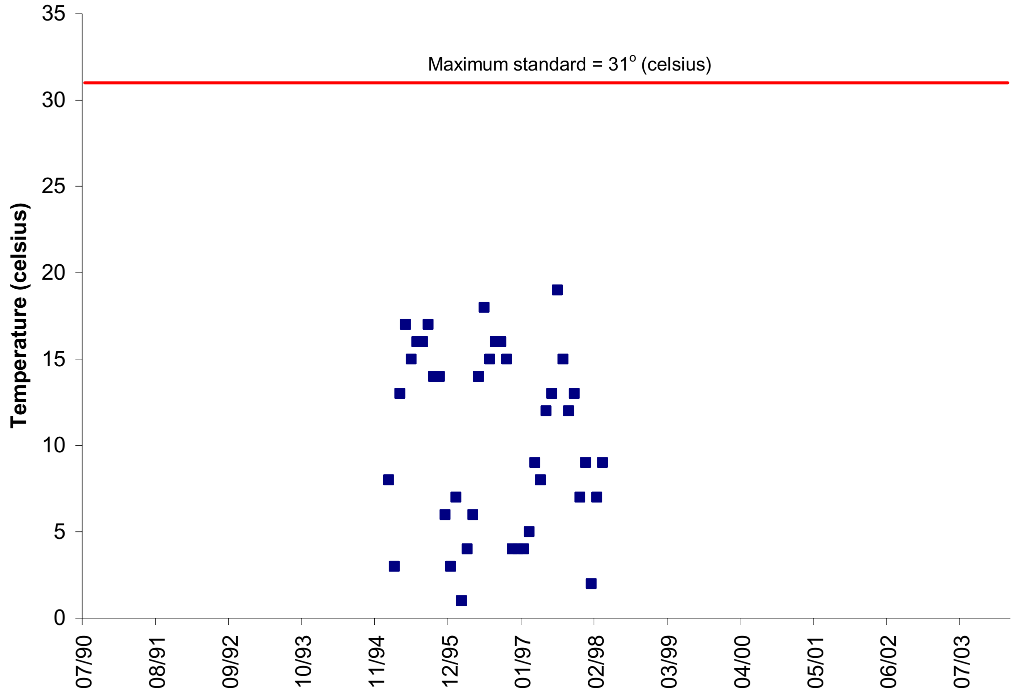

Figure C.15 Temperature values at DMME MPID 1020241.

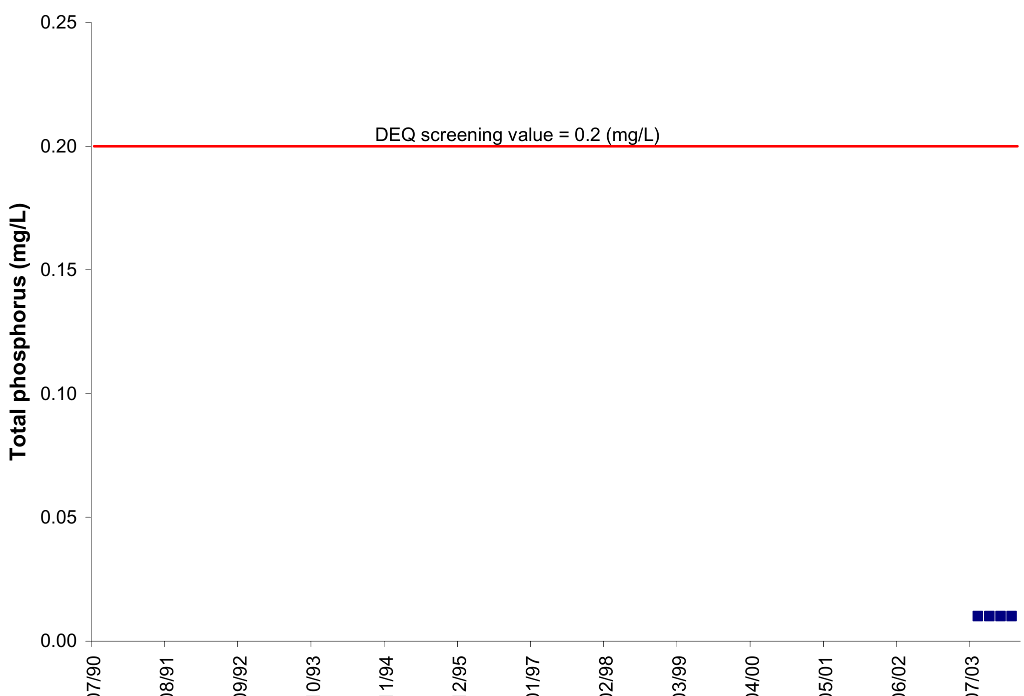

Figure C.16 TP concentrations at VADEQ station 6BSRA000.10.

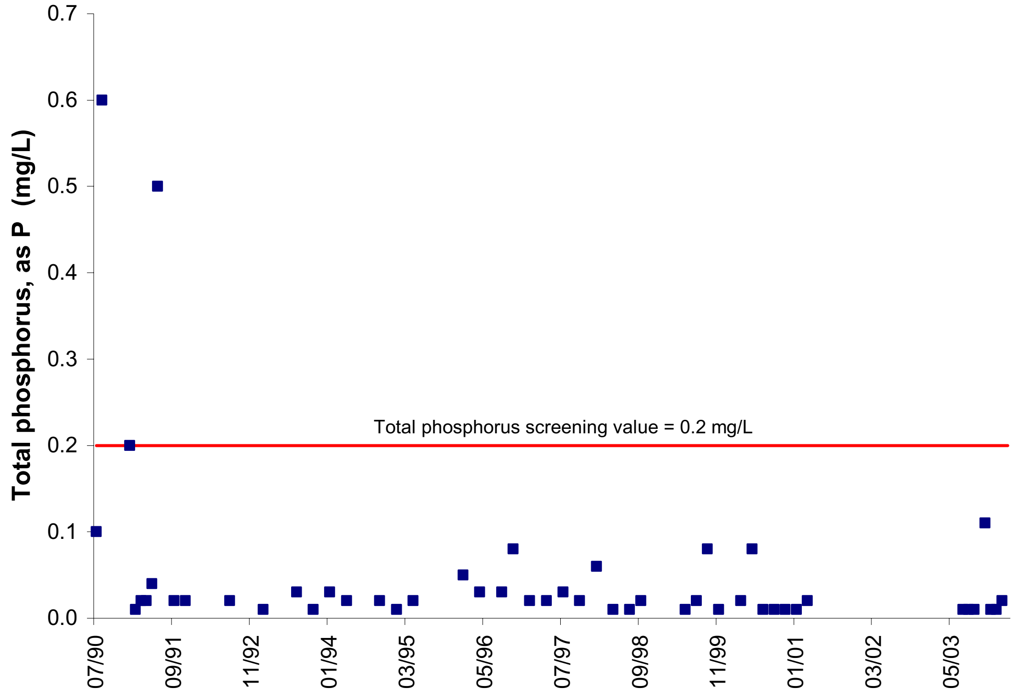

Figure C.17 TP concentrations at VADEQ station 6BSRA001.11.

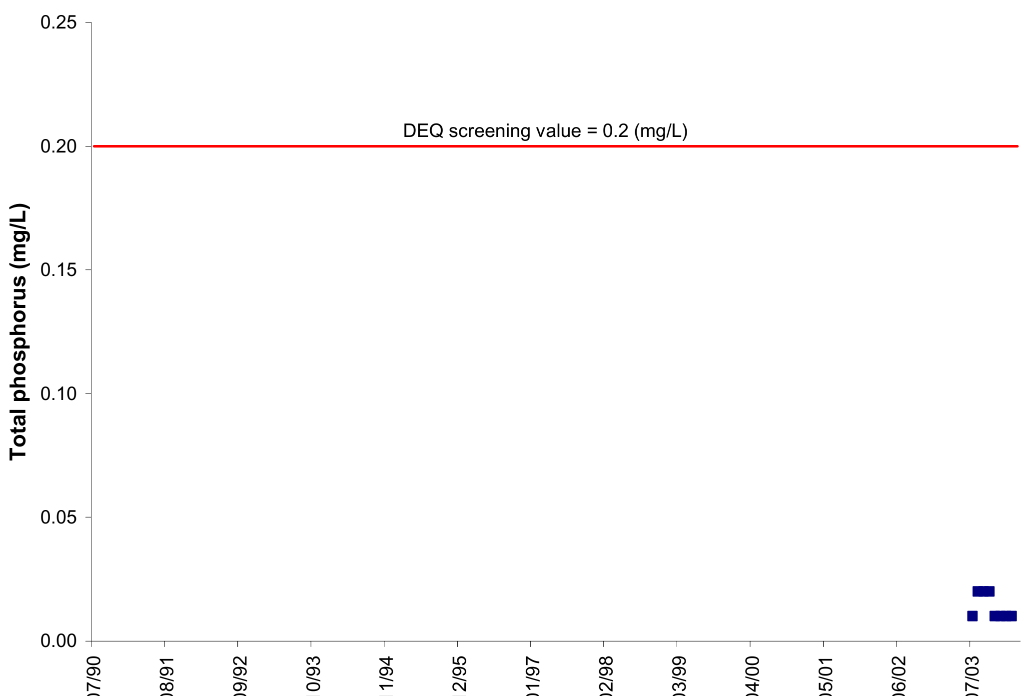

Figure C.18 TP concentrations at VADEQ station 6BSRA003.22.

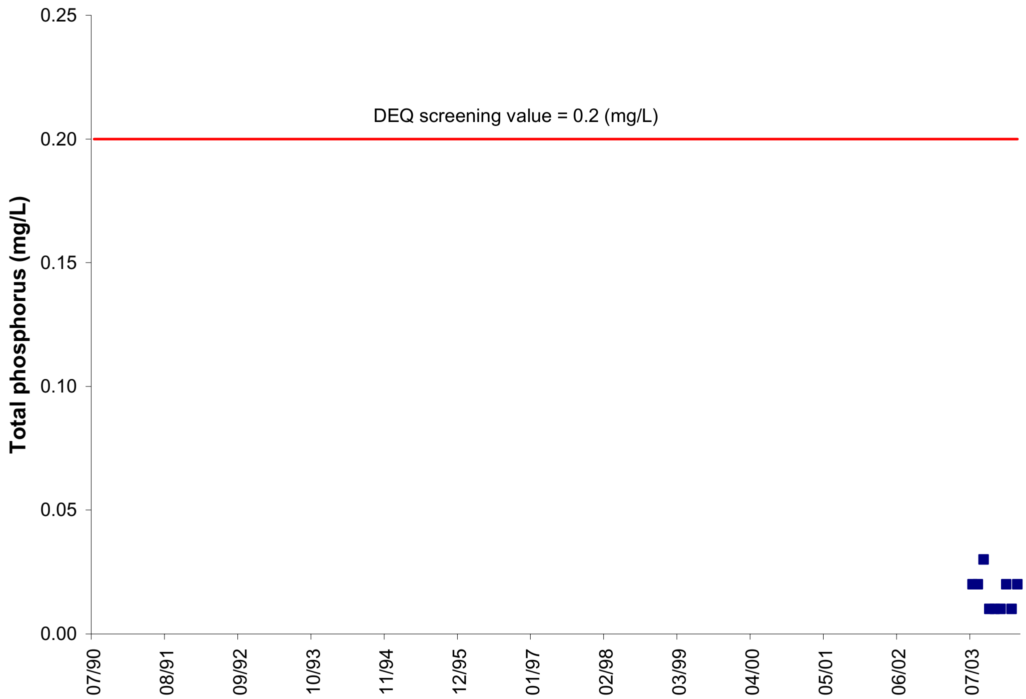

Figure C.19 TP concentrations at VADEQ station 6BSRA004.16.

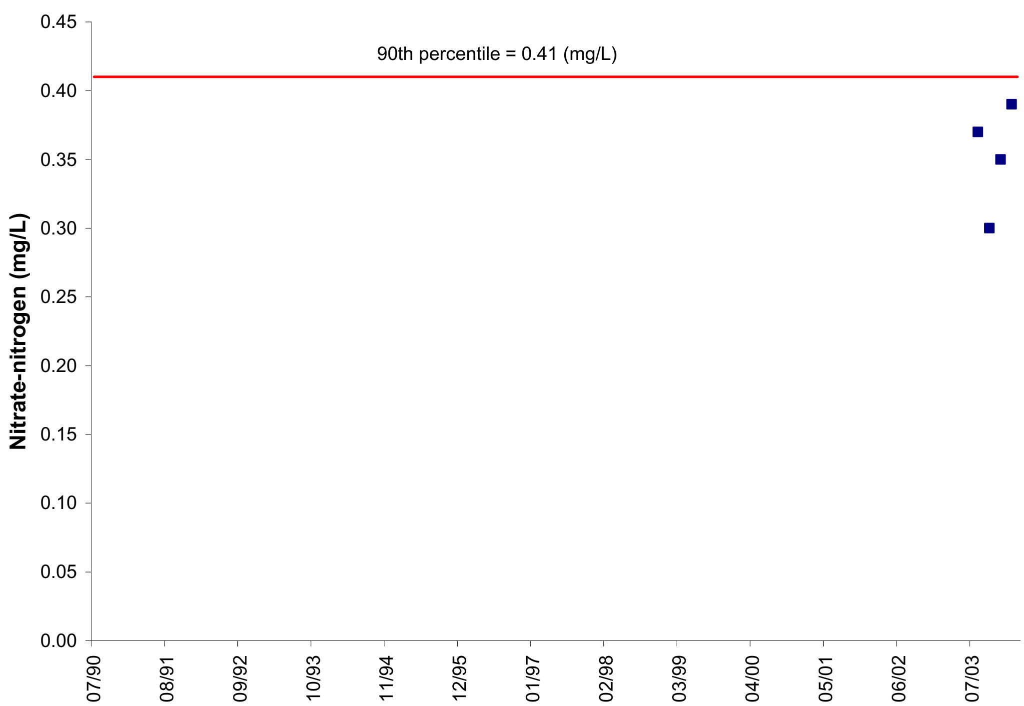

Figure C.20 NO3-N concentrations at VADEQ station 6BSRA000.10.

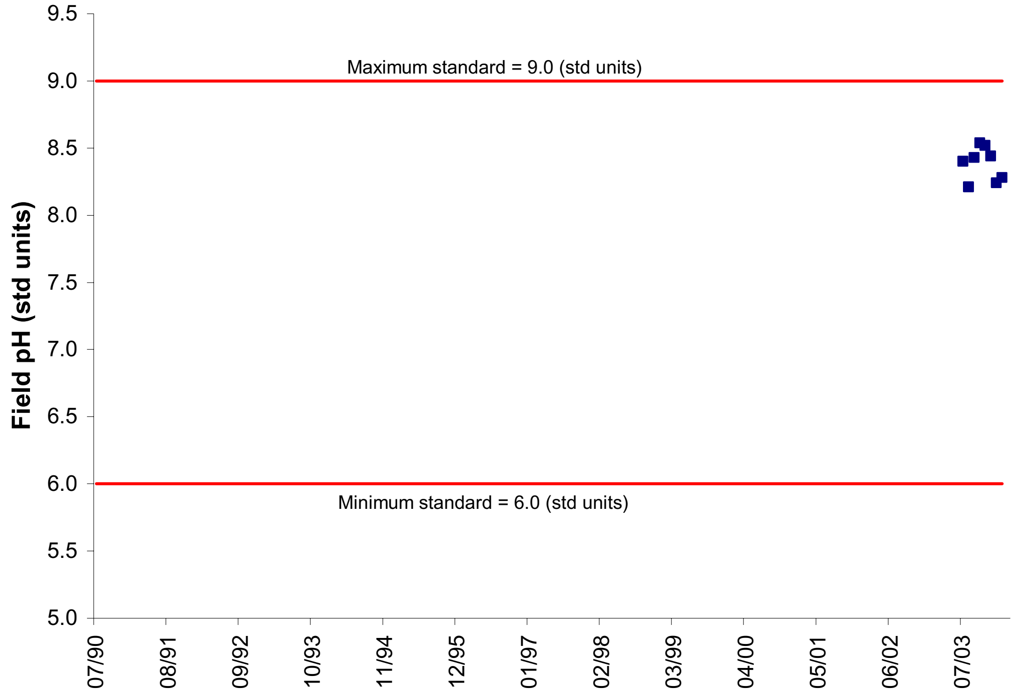

Figure C.21 Field pH values at VADEQ station 6BSRA003.22.

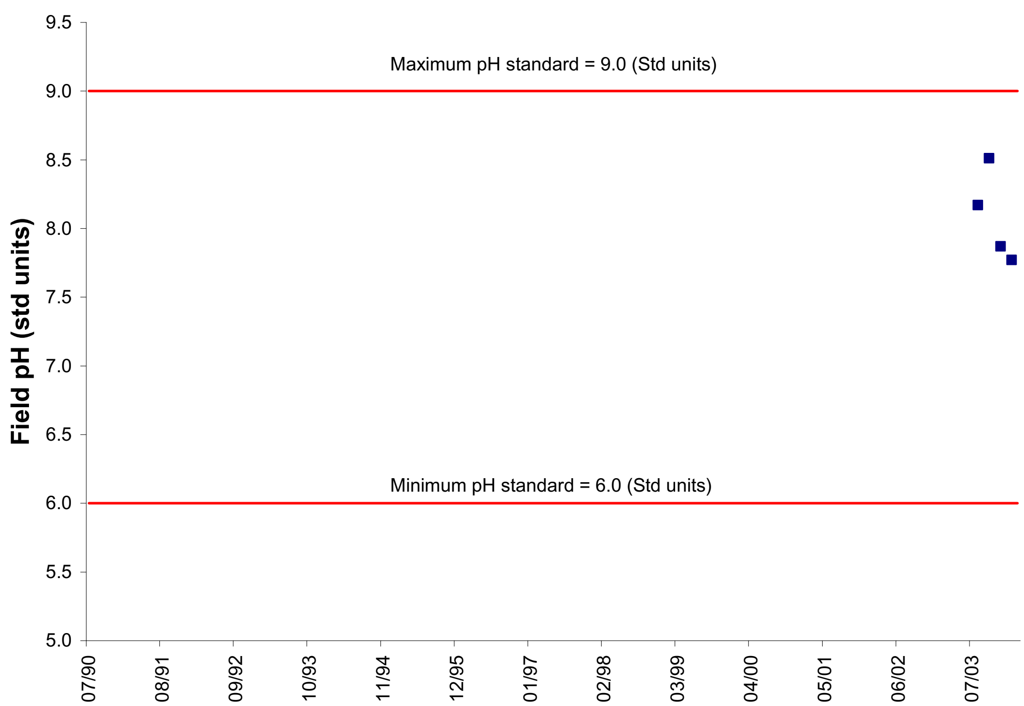

Figure C.22 Field pH values at VADEQ station 6BSRA000.10.

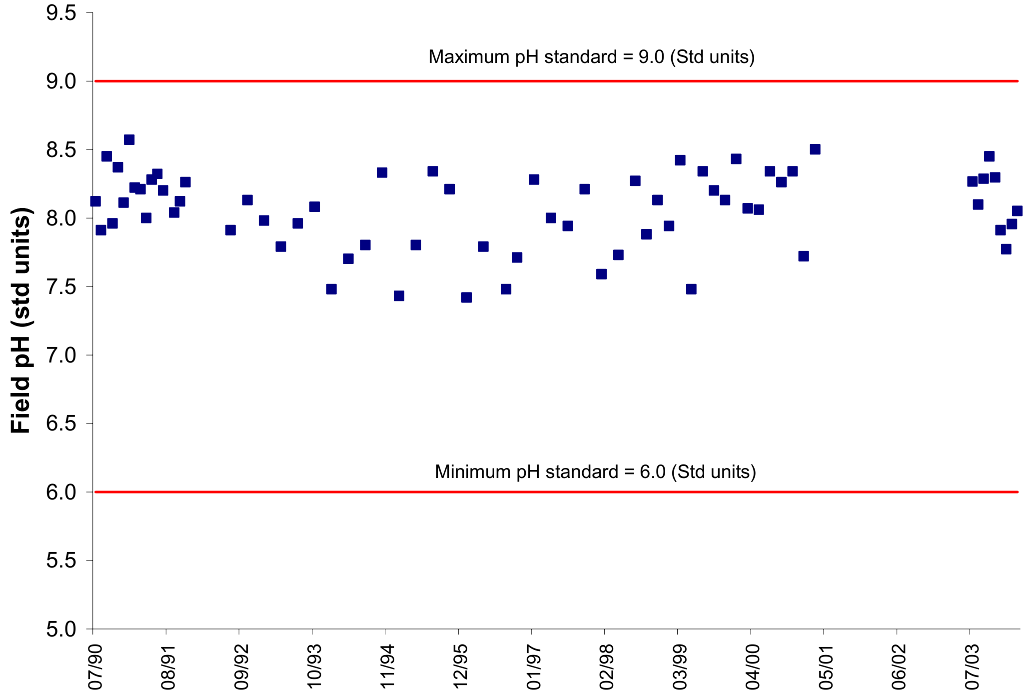

Figure C.23 Field pH values at VADEQ station 6BSRA001.11.

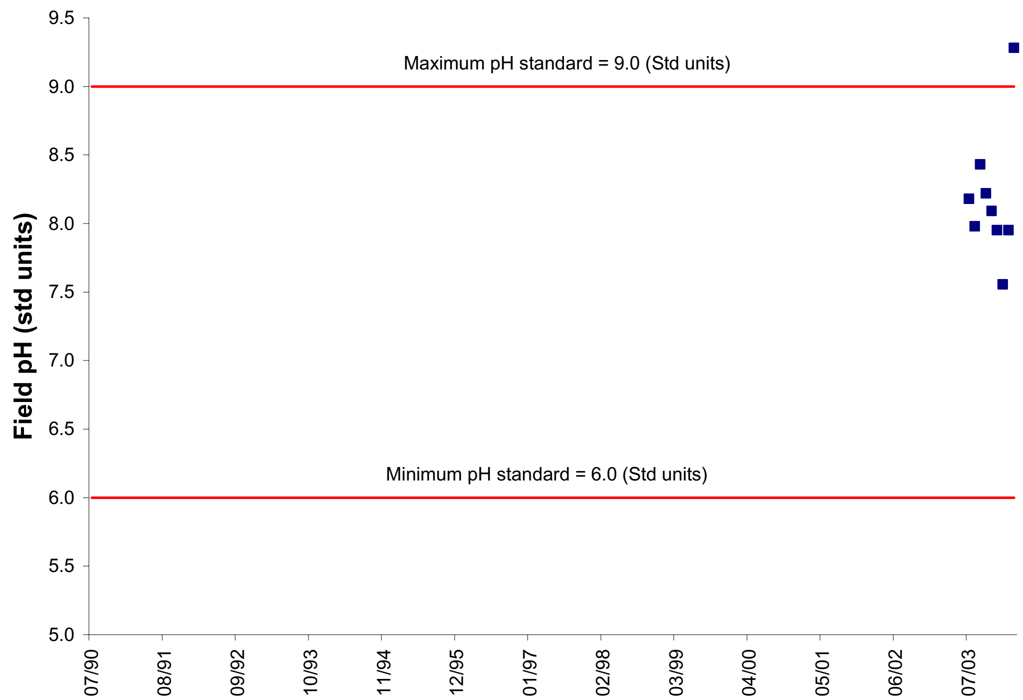

Figure C.24 Field pH values at VADEQ station 6BSRA004.16.

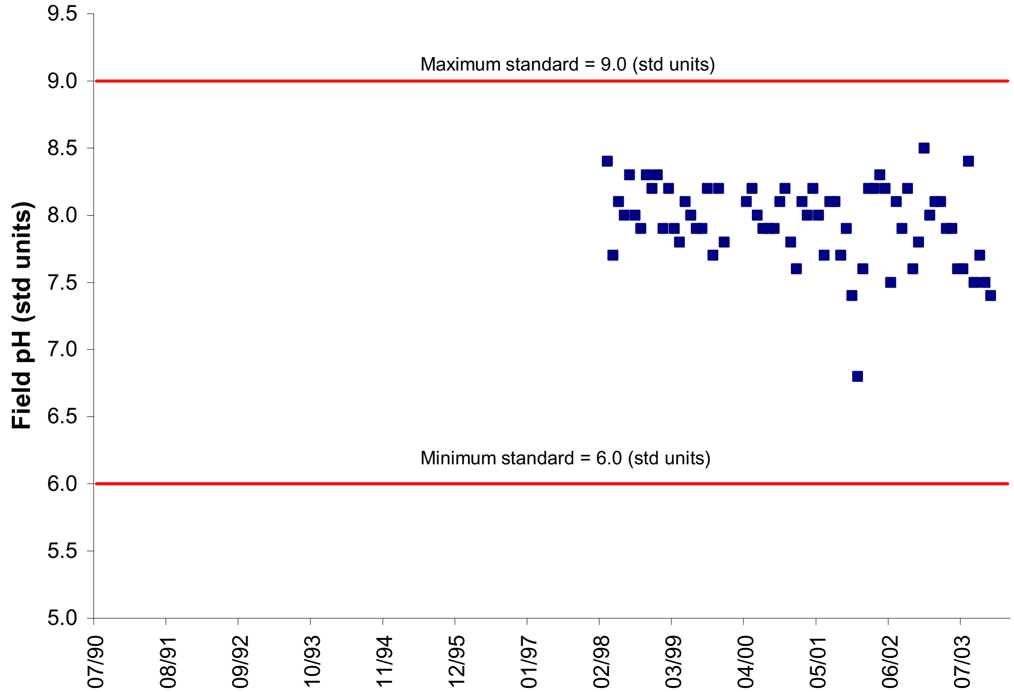

Figure C.25 Field pH values at DMME MPID 0002877.

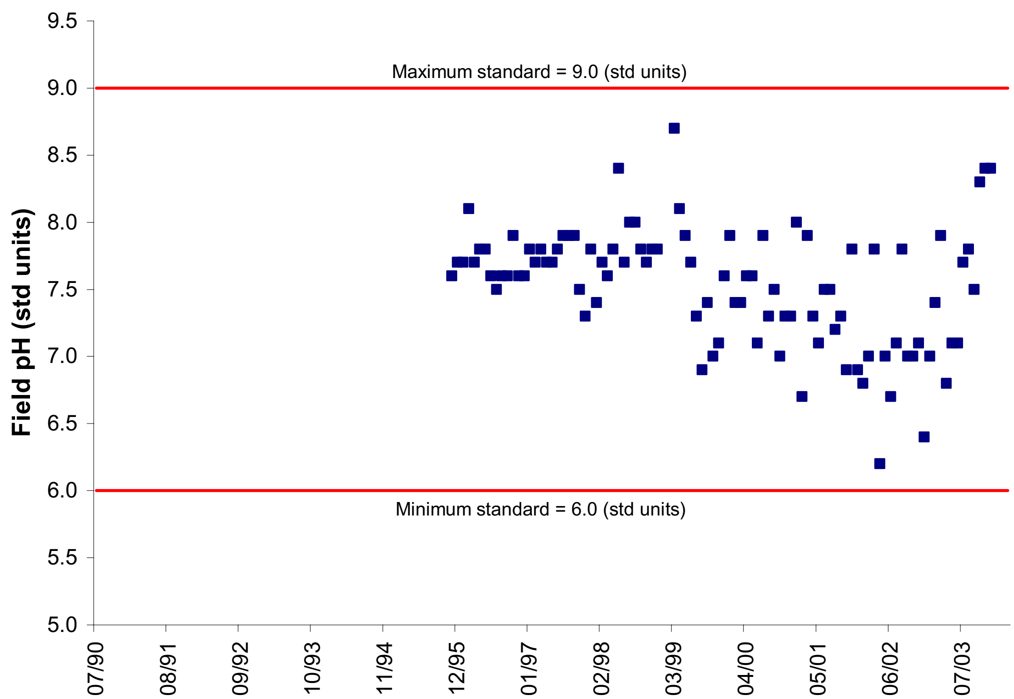

Figure C.26 Field pH values at DMME MPID 1020127.

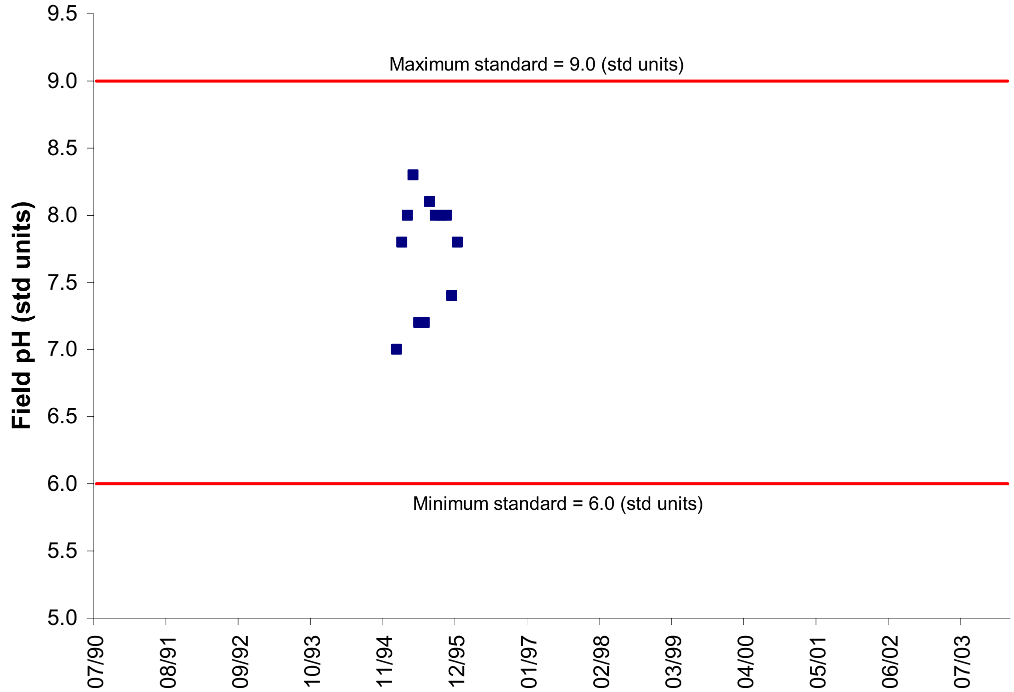

Figure C.27 Field pH values at DMME MPID 1020209.

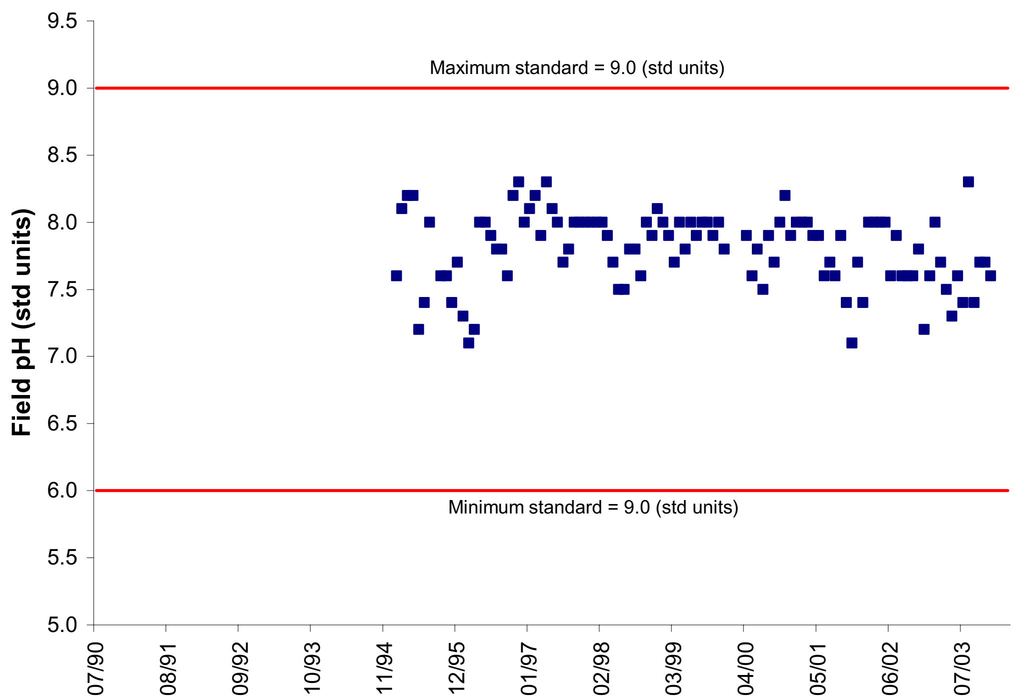

Figure C.28 Field pH values at DMME MPID 1020225.

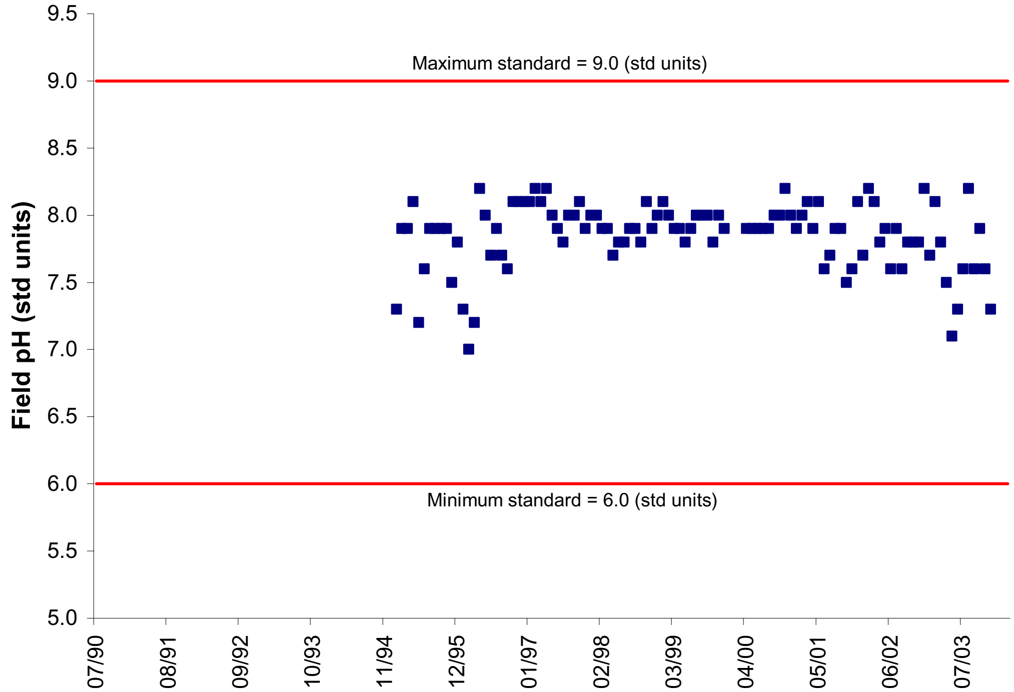

Figure C.29 Field pH values at DMME MPID 1020226.

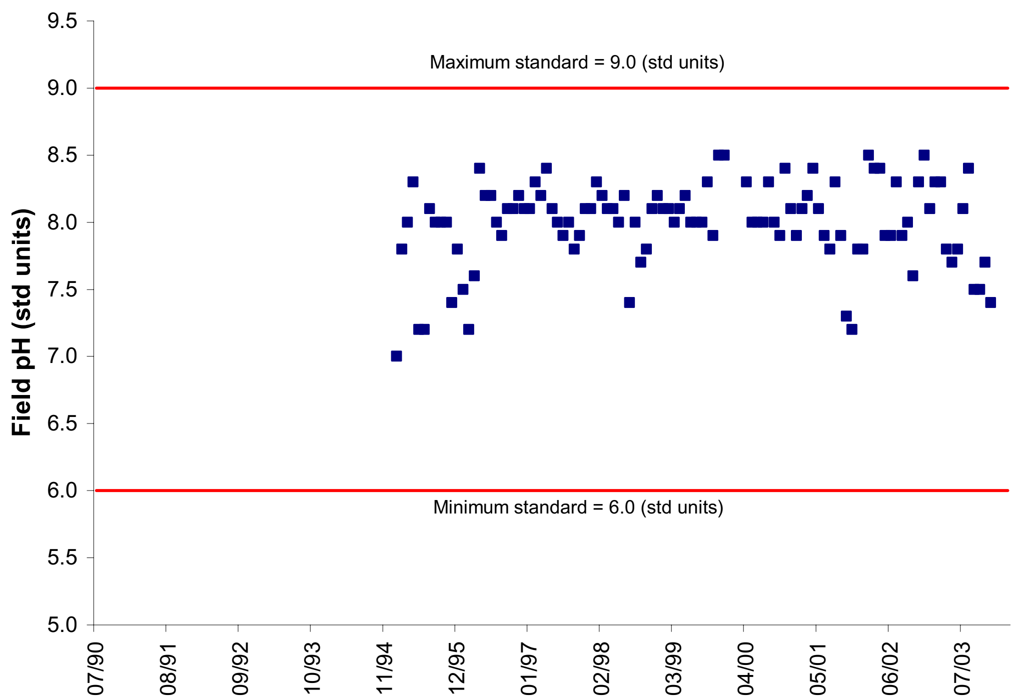

Figure C.30 Field pH values at DMME MPID 1020237.

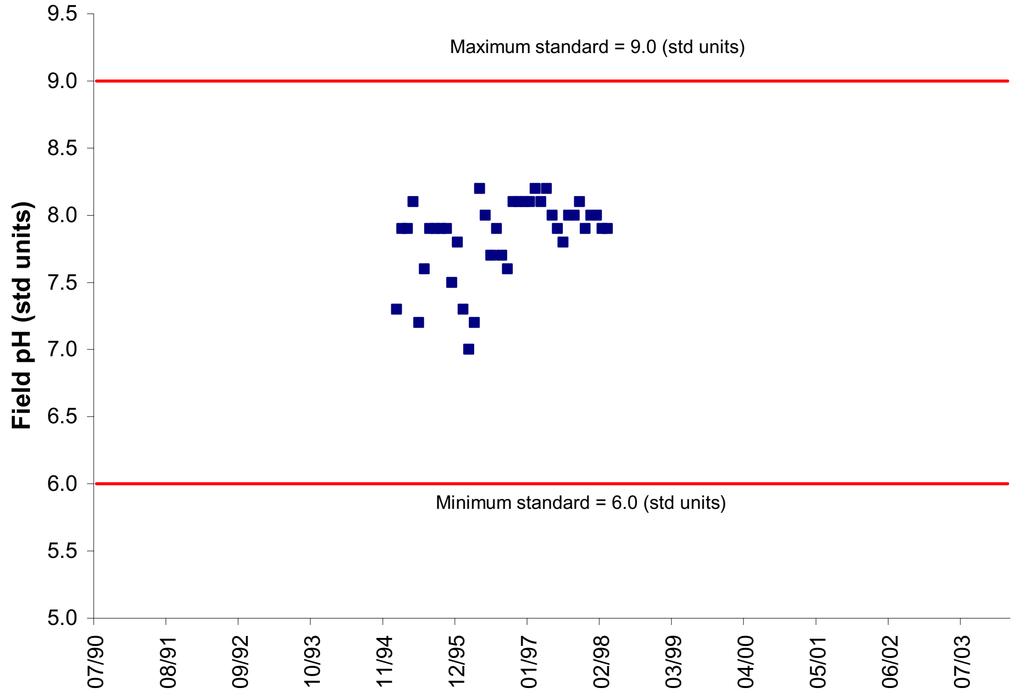

Figure C.31 Field pH values at DMME MPID 1020241.

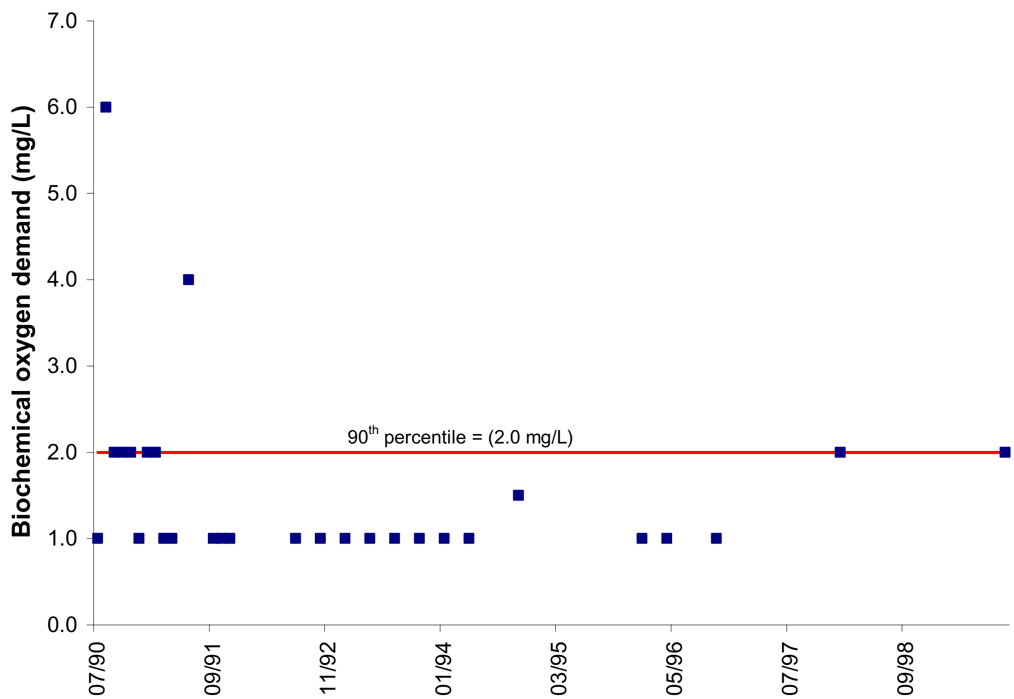

Figure C.32 BOD_5 concentrations at VADEQ station 6BSRA001.11.

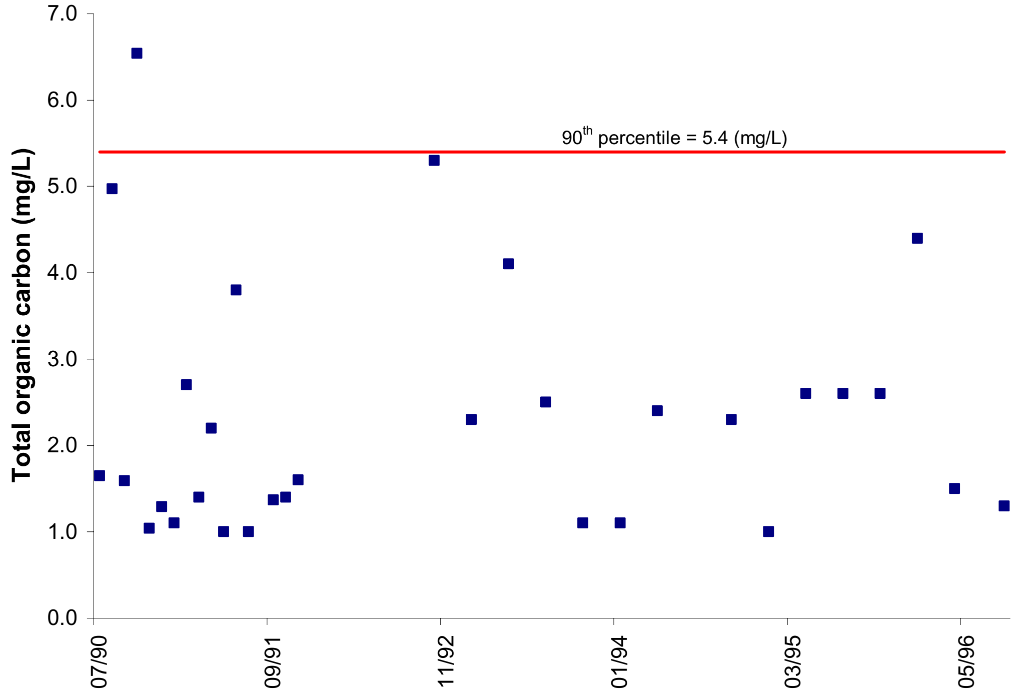

Figure C.33 TOC concentrations at VADEQ station 6BSRA001.11.

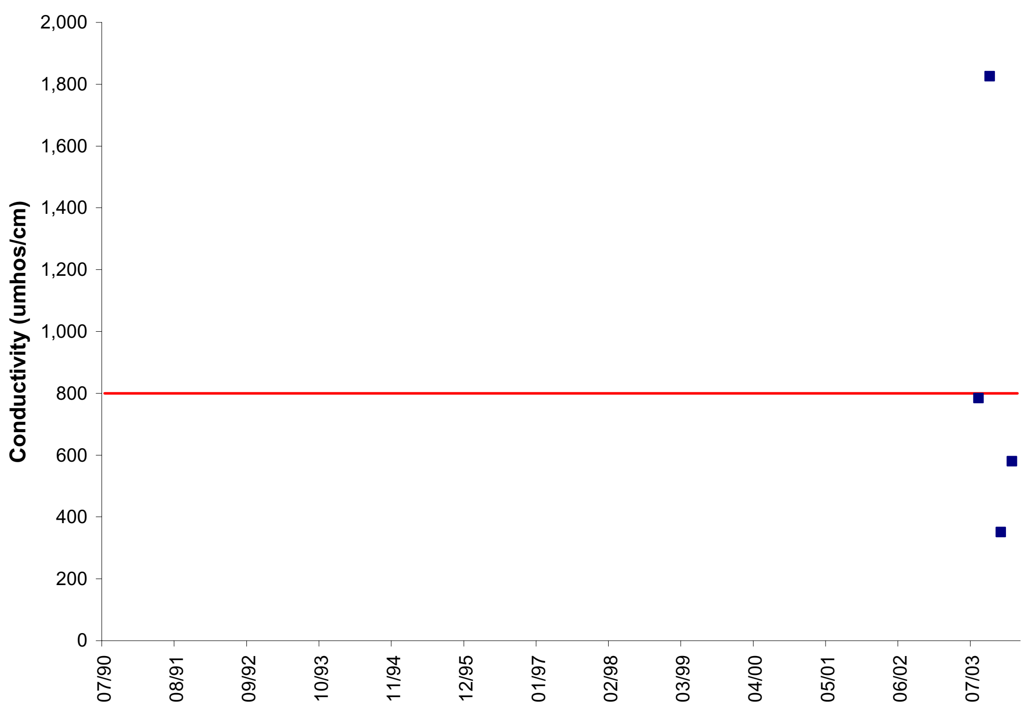

Figure C.34 Conductivity values at VADEQ station 6BSRA000.10.

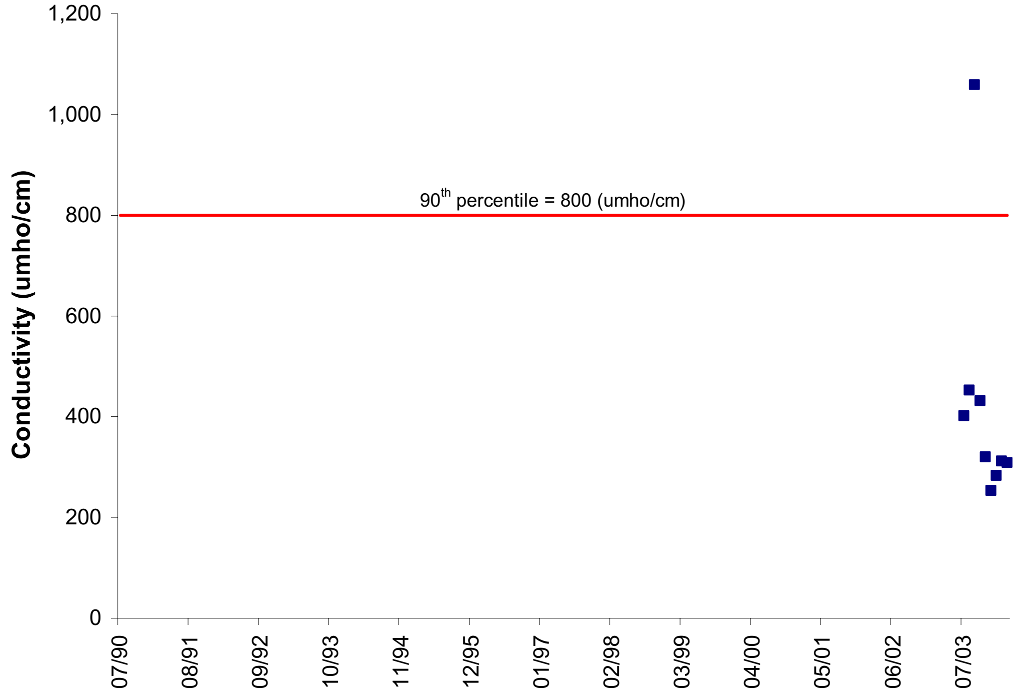

Figure C.35 Conductivity values at VADEQ station 6BSRA004.16.

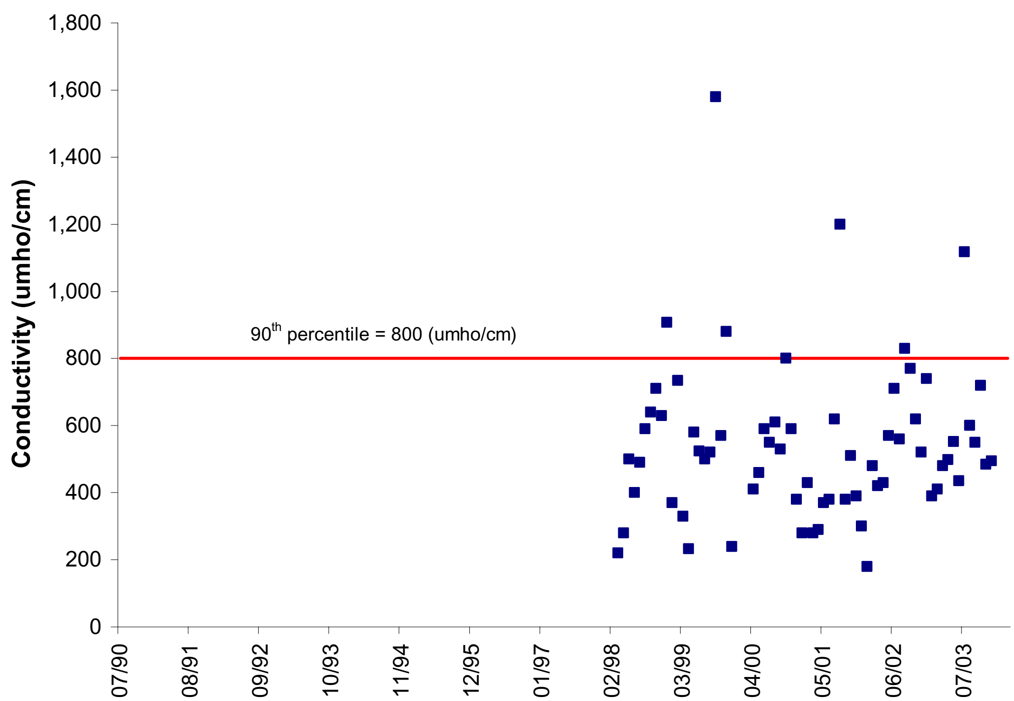

Figure C.36 Conductivity values at DMME MPID 0002877.

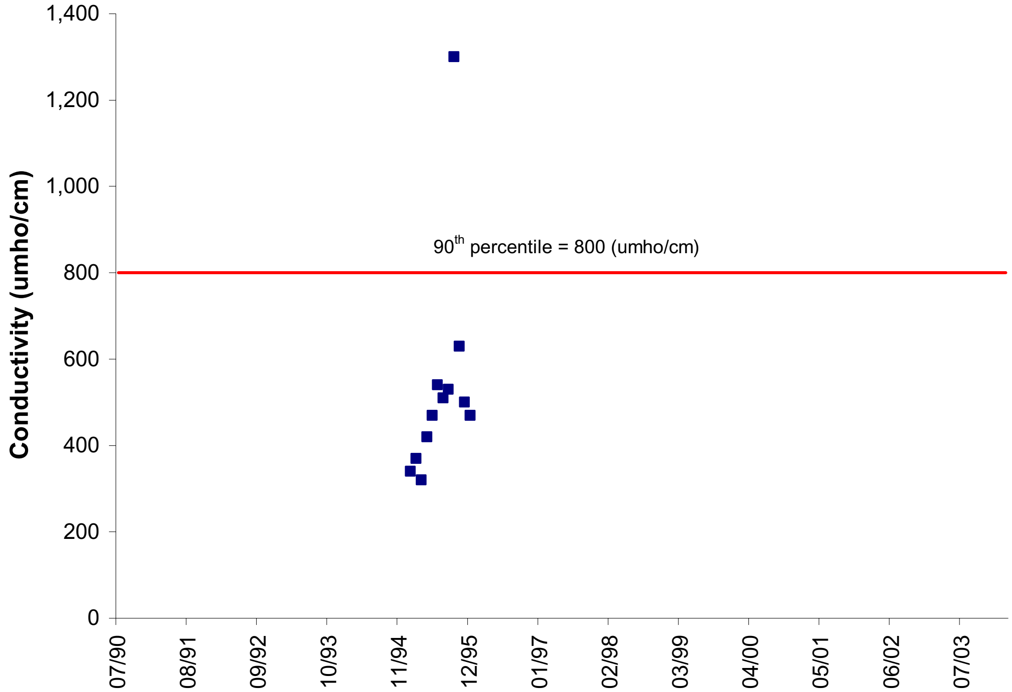

Figure C.37 Conductivity values at DMME MPID 1020209.

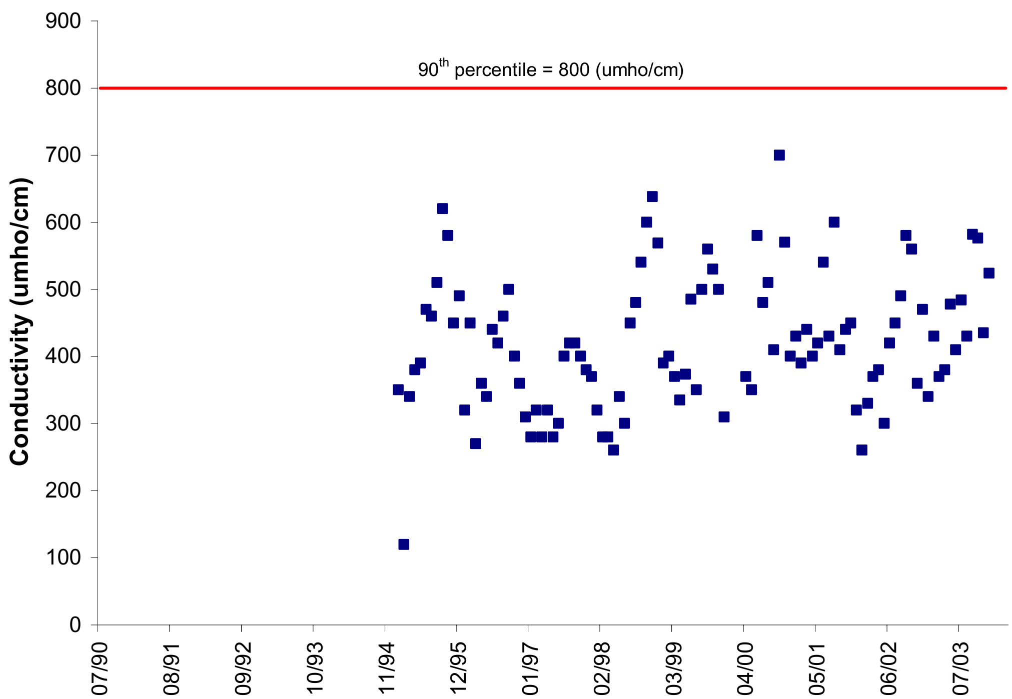

Figure C.38 Conductivity values at DMME MPID 1020225.

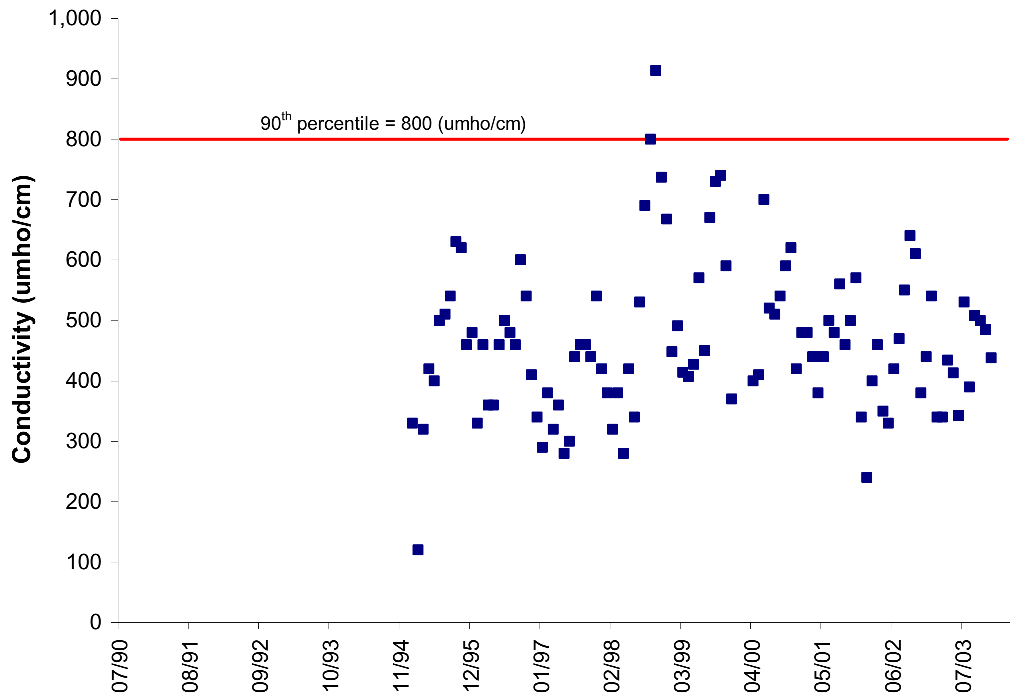

Figure C.39 Conductivity values at DMME MPID 1020226.

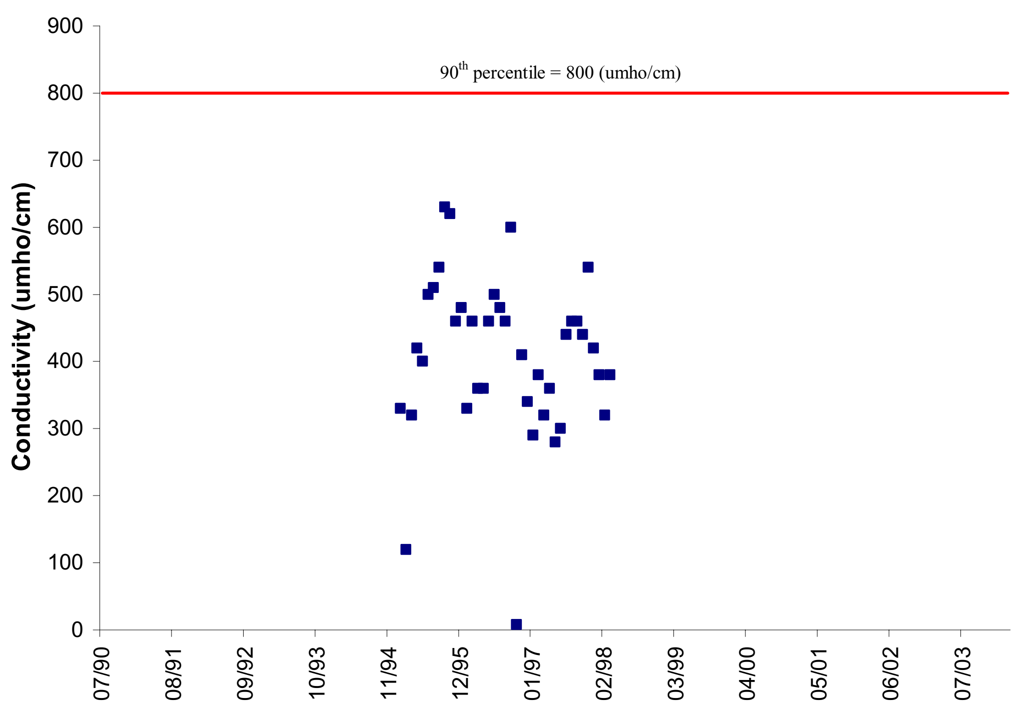

Figure C.40 Conductivity values at DMME MPID 1020241.

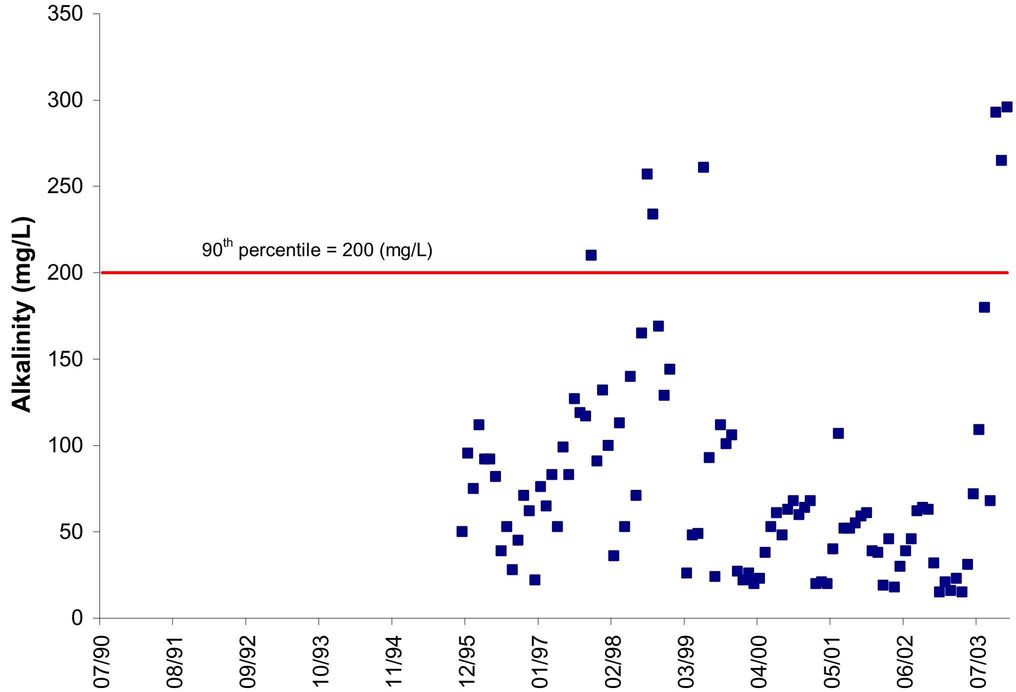

Figure C.41 Alkalinity concentrations at DMME MPID 1020127.

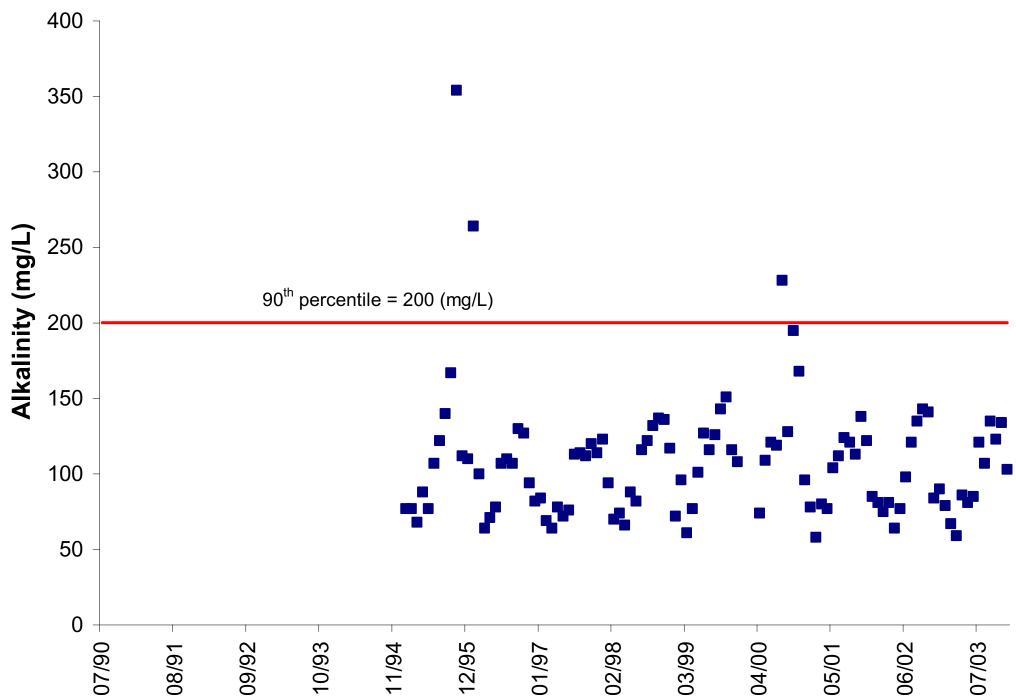

Figure C.42 Alkalinity concentrations at DMME MPID 1020225.

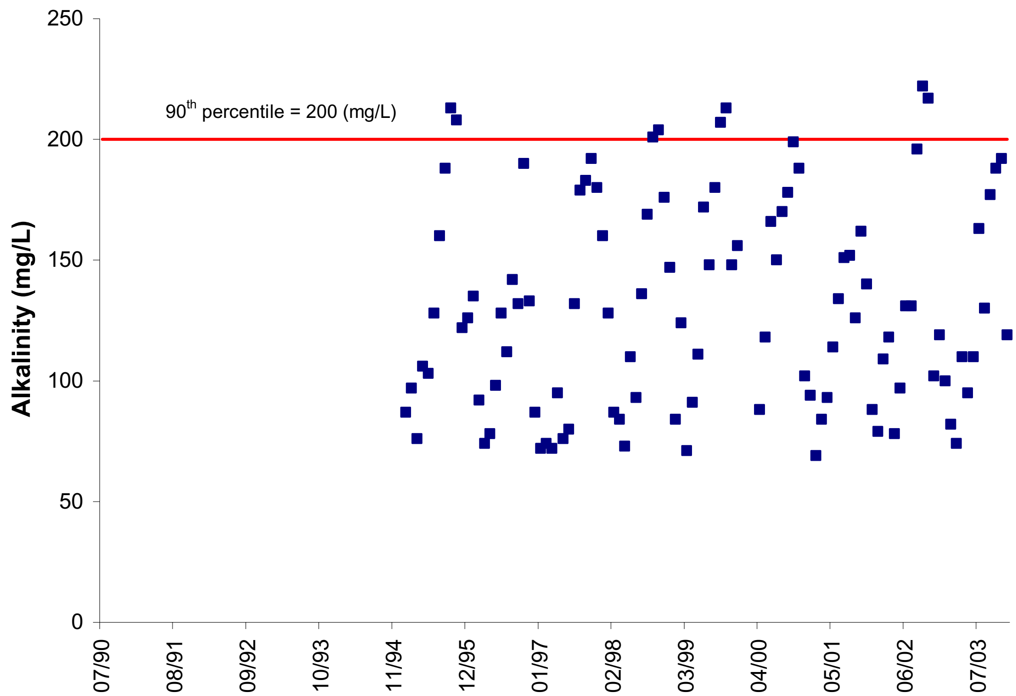

Figure C.43 Alkalinity concentrations at DMME MPID 1020226.

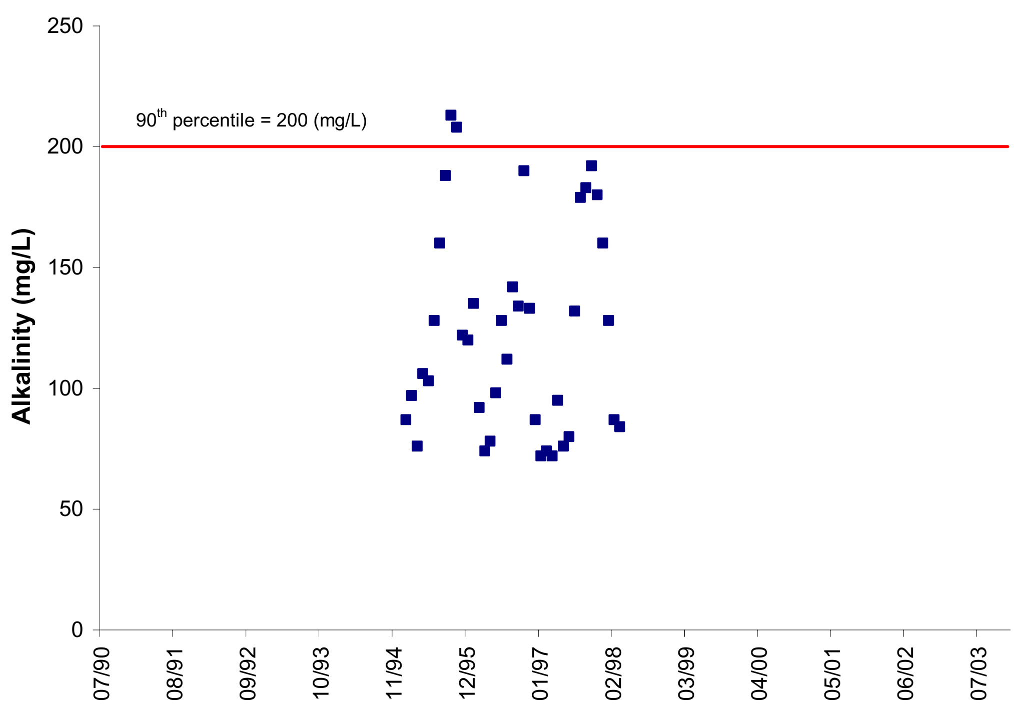

Figure C.44 Alkalinity concentrations at DMME MPID 1020241.

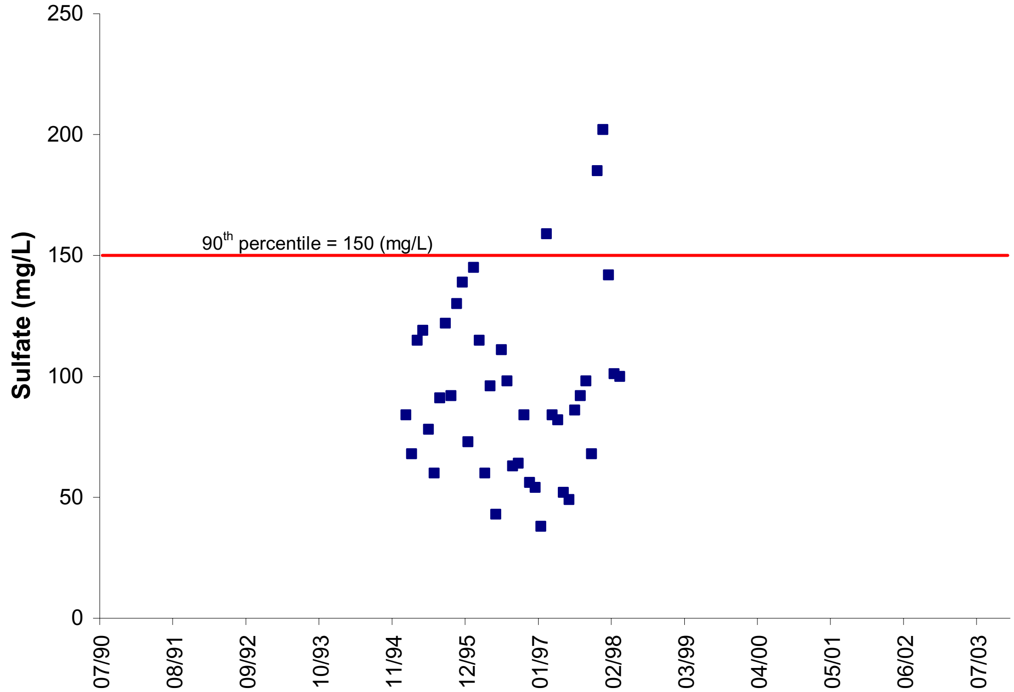

Figure C.45 Sulfate concentrations at DMME MPID 1020241.

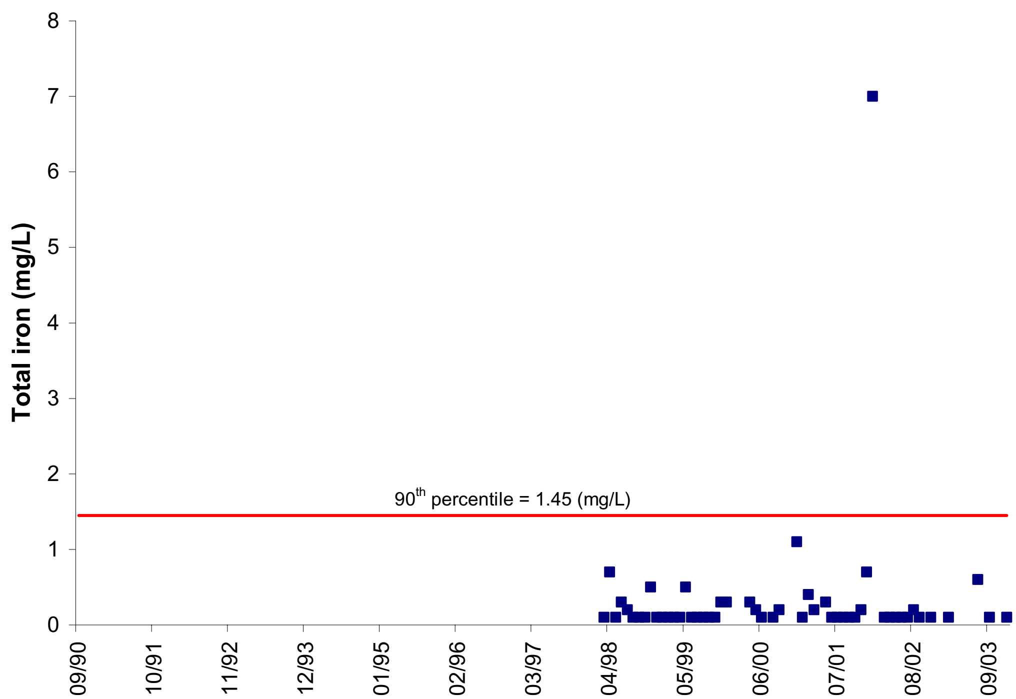

Figure C.46 Total iron concentrations at DMME MPID 0002877.

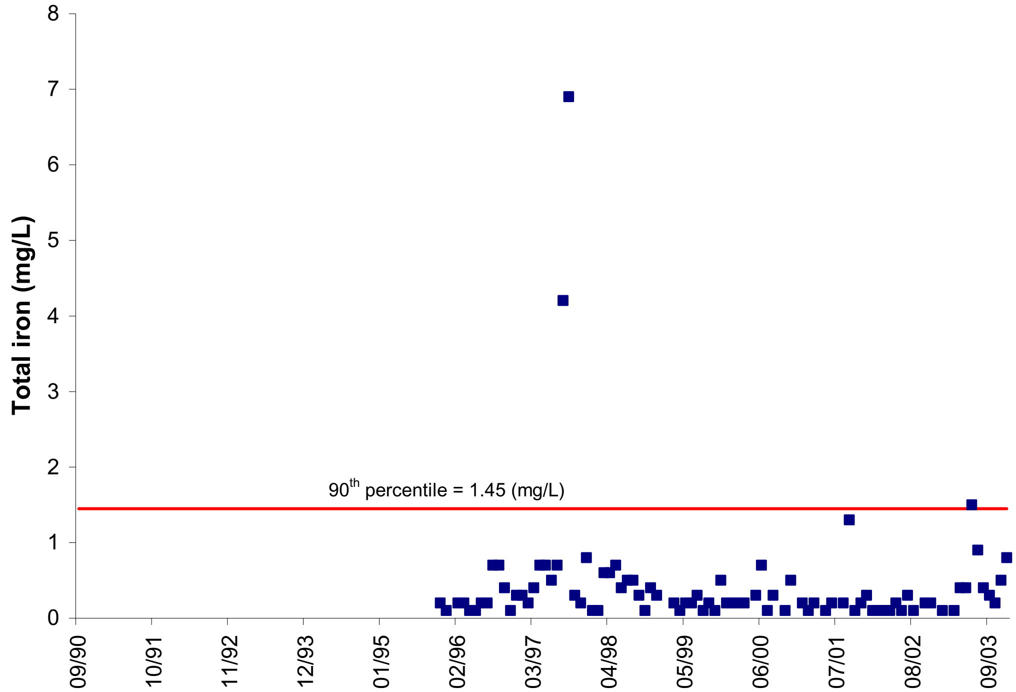

Figure C.47 Total iron concentrations at DMME MPID 1020127.

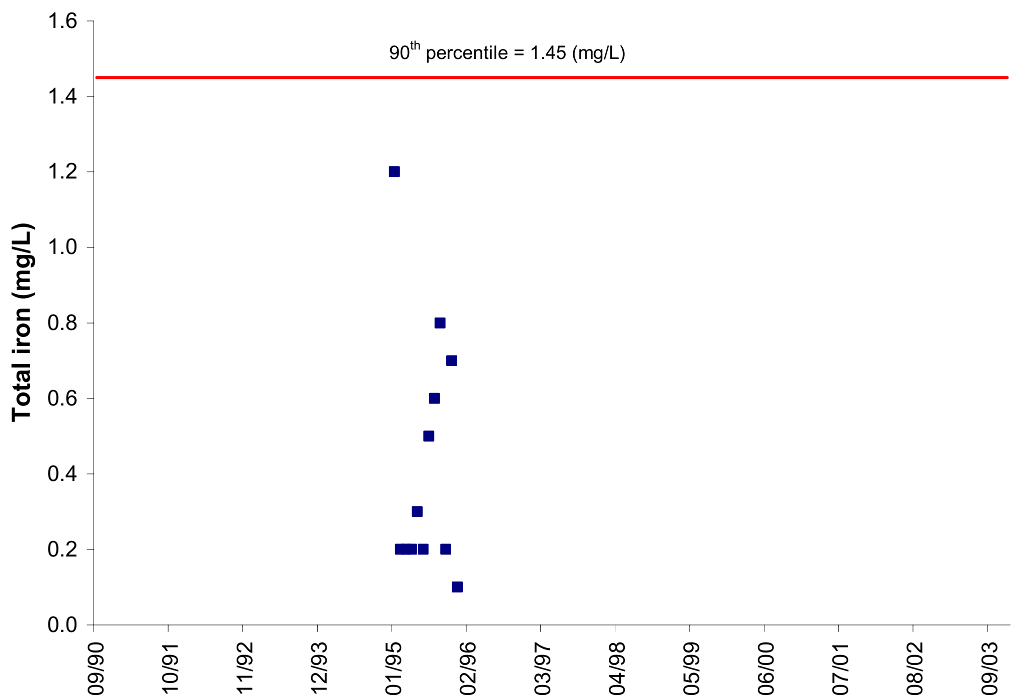

Figure C.48 Total iron concentrations at DMME MPID 1020209.

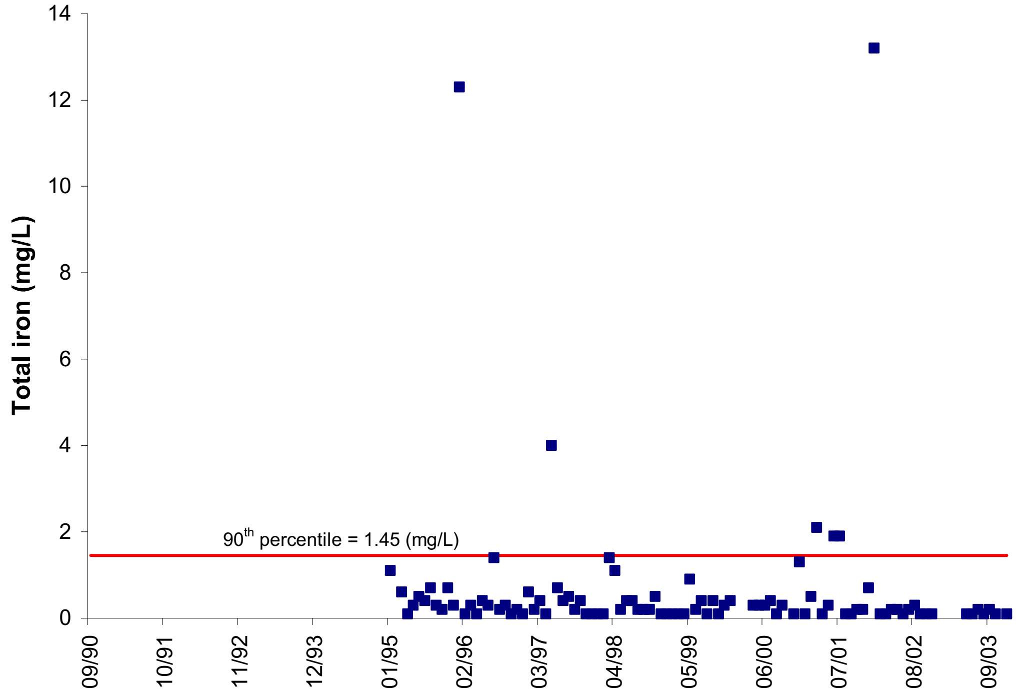

Figure C.49 Total iron concentrations at DMME MPID 1020225.

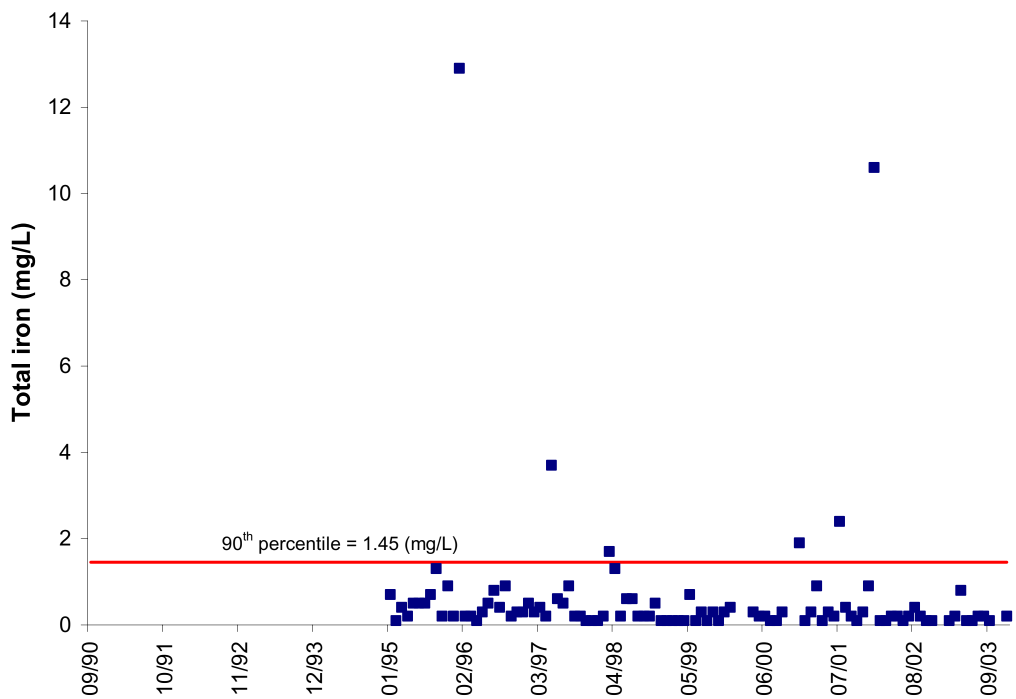

Figure C.50 Total iron concentrations at DMME MPID 1020226.

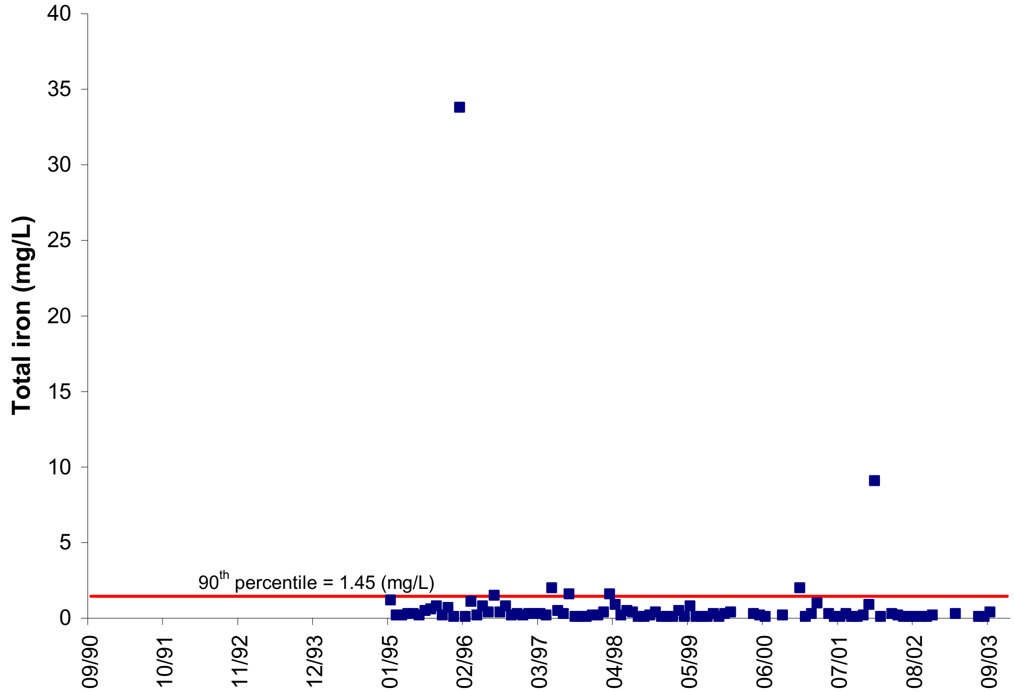

Figure C.51 Total iron concentrations at DMME MPID 1020237.

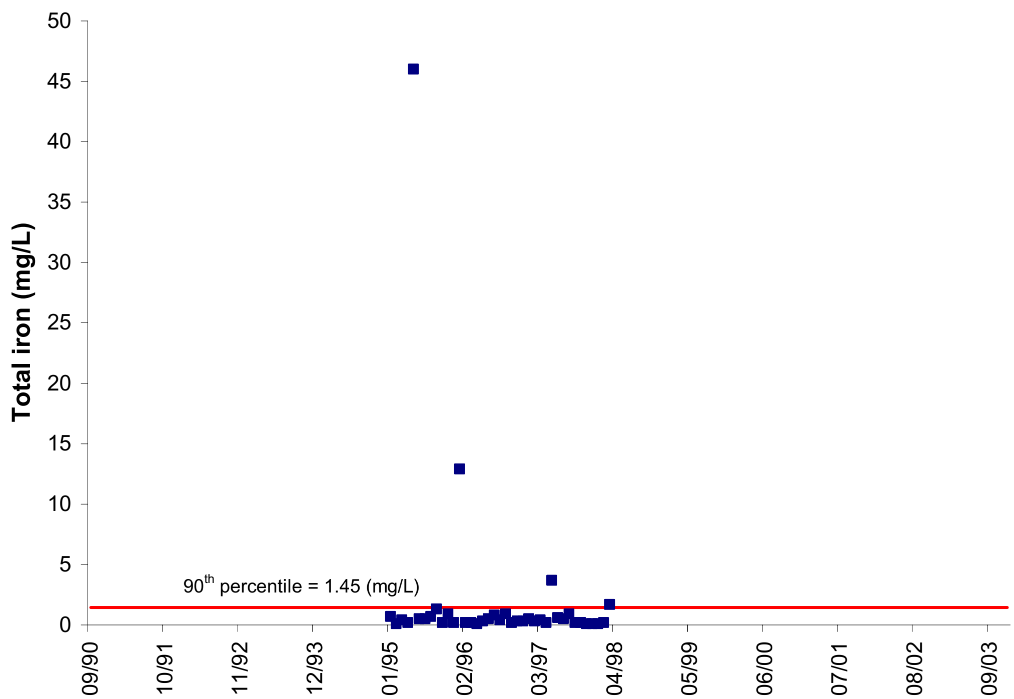

Figure C.52 Total iron concentrations at DMME MPID 1020241.

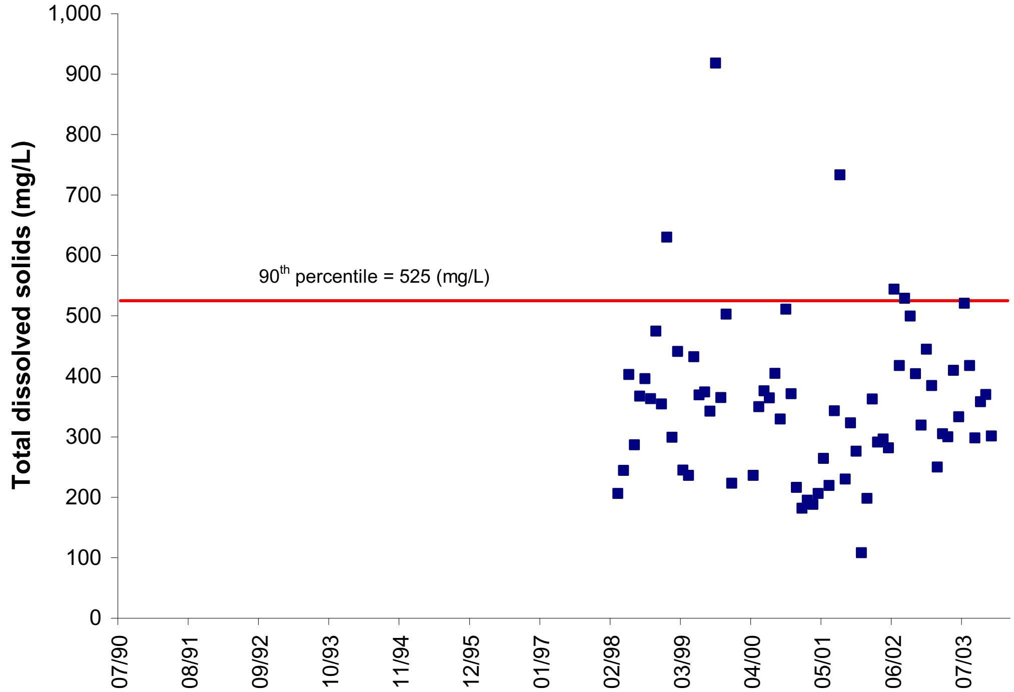

Figure C.53 Total dissolved solids concentrations at DMME MPID 0002877.

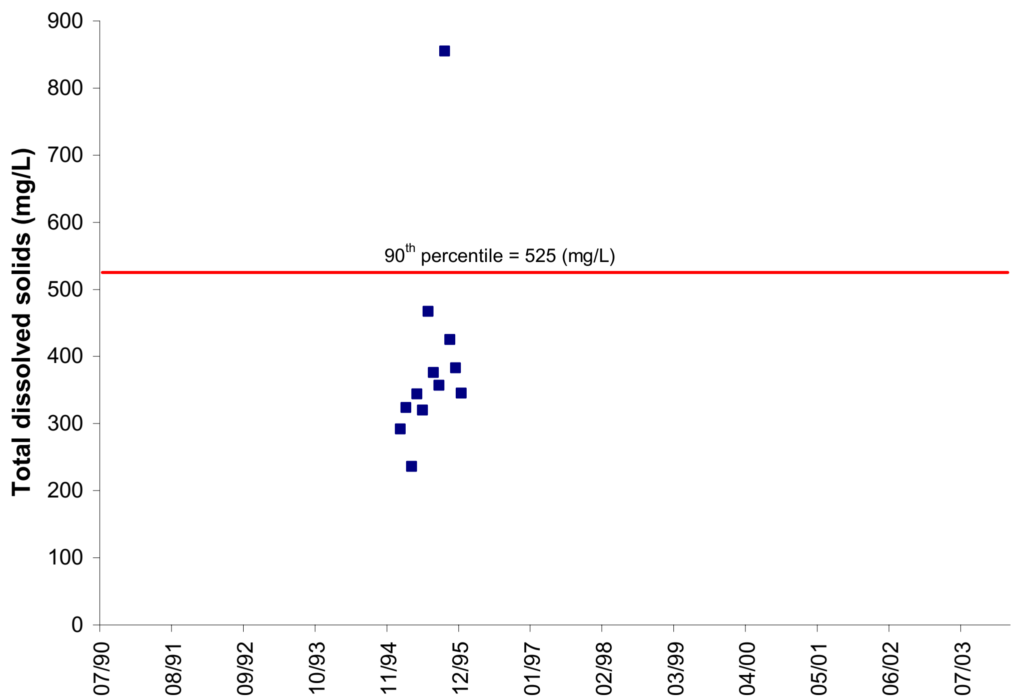

Figure C.54 Total dissolved solids concentrations at DMME MPID 1020209.

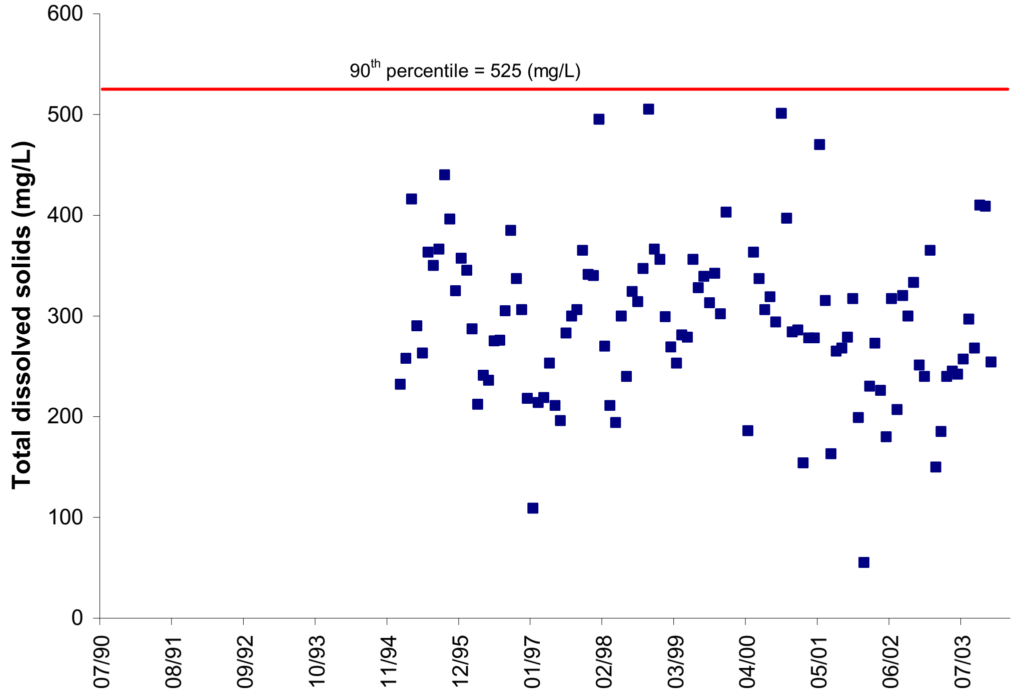

Figure C.55 Total dissolved solids concentrations at DMME MPID 1020225.

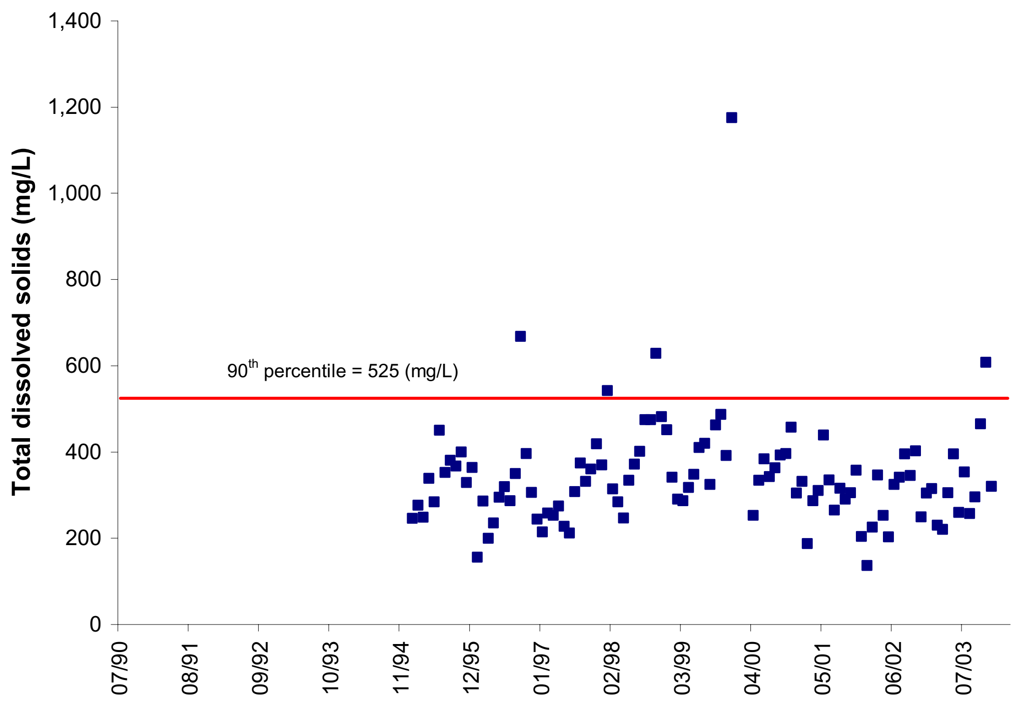

Figure C.56 Total dissolved solids concentrations at DMME MPID 1020226.

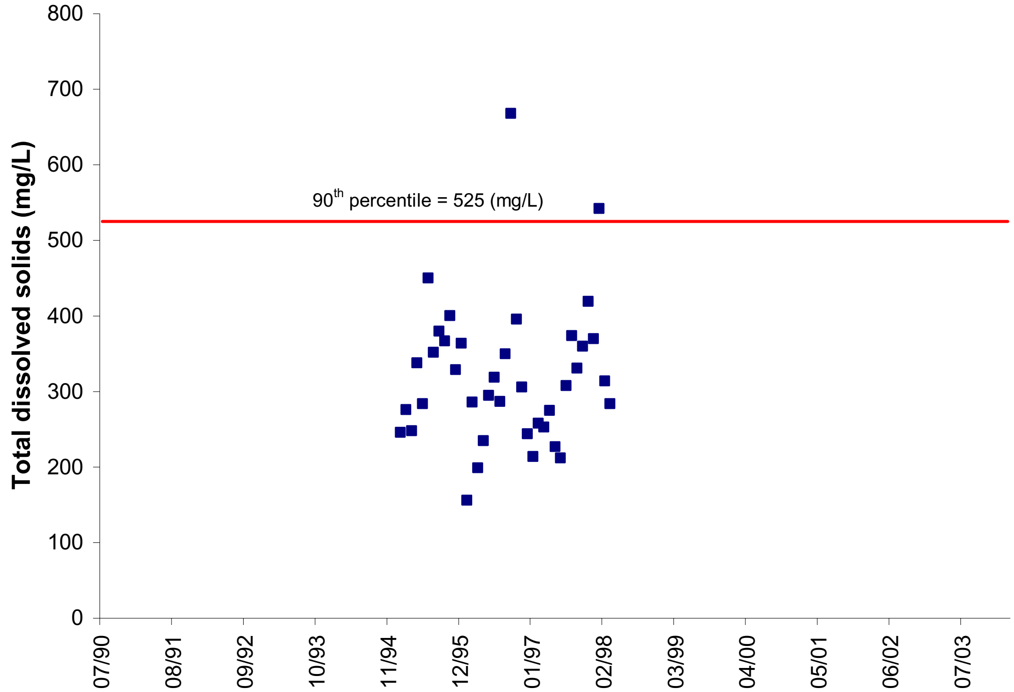

Figure C.57 Total dissolved solids concentrations at DMME MPID 1020241.

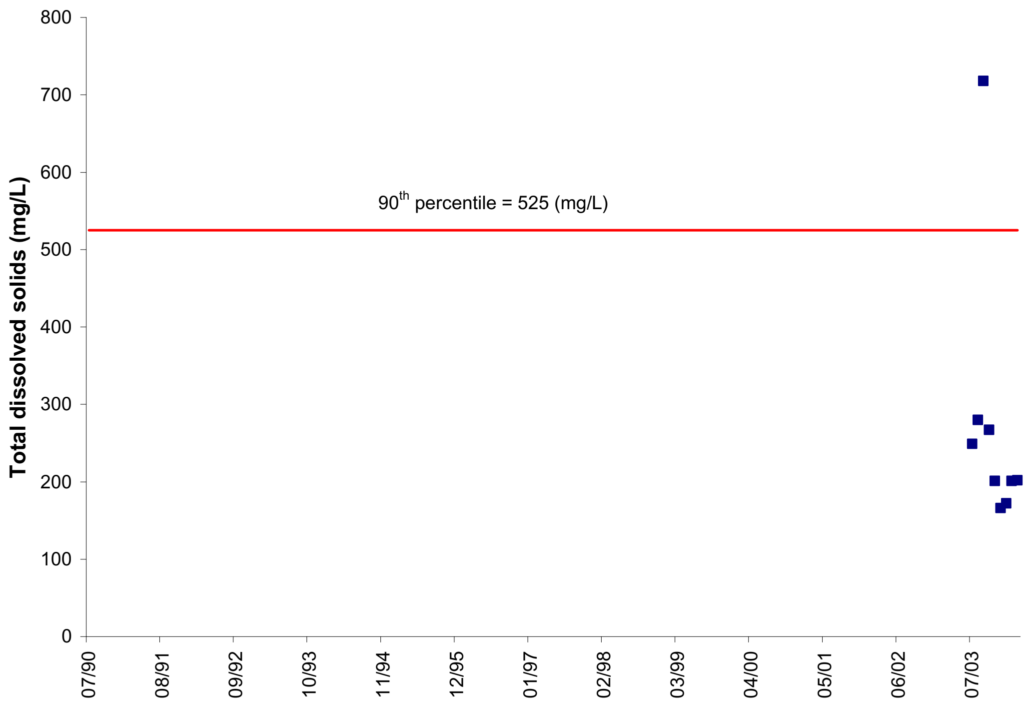

Figure C.58 TDS concentrations at VADEQ station 6BSRA004.16.

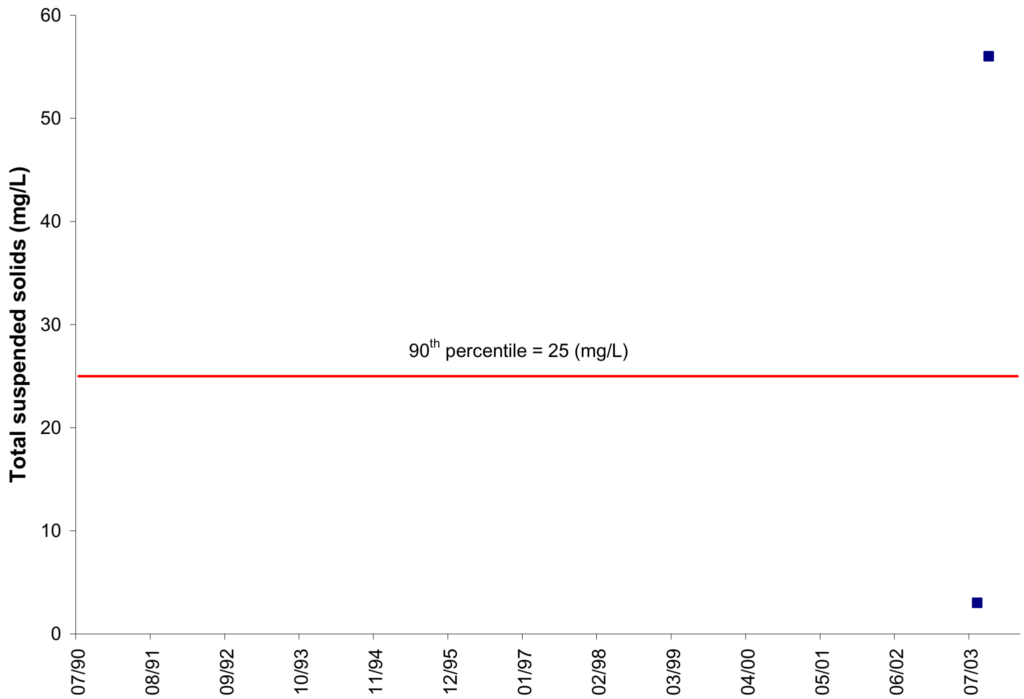

Figure C.59 TSS concentrations at VADEQ station 6BSRA003.22.

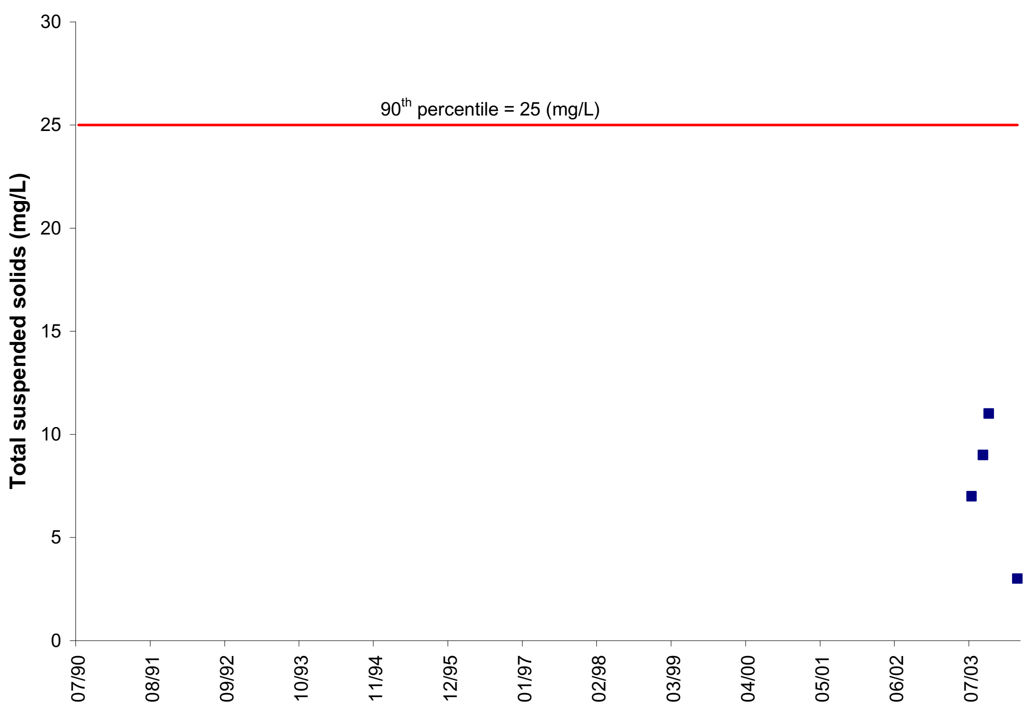

Figure C.60 TSS concentrations at VADEQ station 6BSRA004.16.

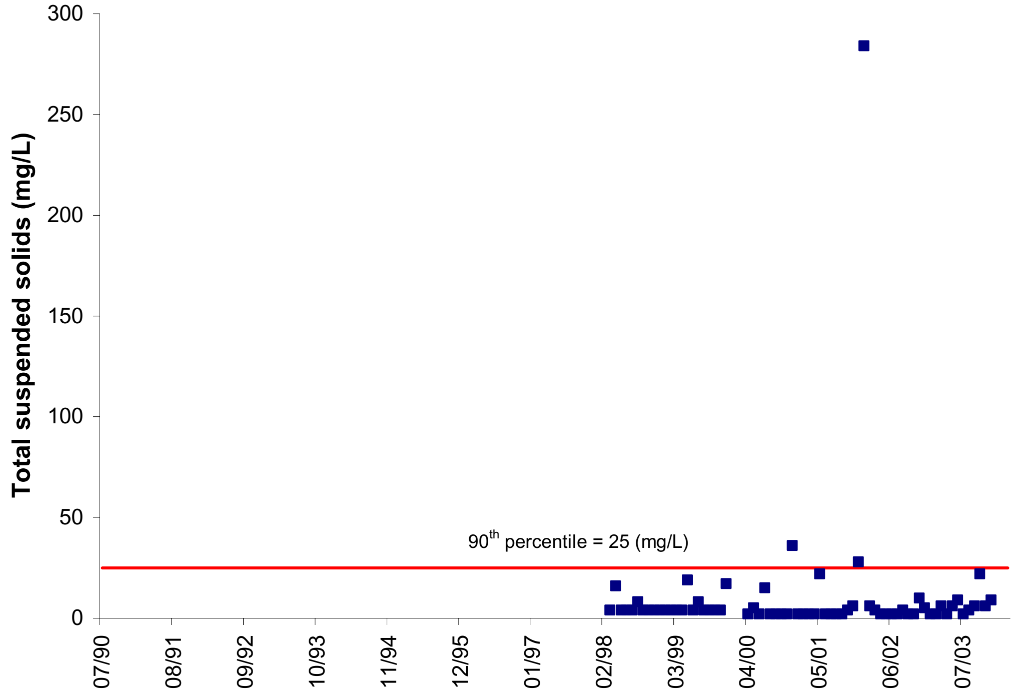

Figure C.61 Total suspended solids concentrations at DMME MPID 0002877.

Table C.1 VADEQ special study organics sediment data in Straight Creek.

Date			8/13/97	6/18/02
PARAM*	PEC*	VA 99th Percentile	6BSRA001.34	6BSRA001.11
Total PAH[1]	22,800		4,503.30	4,275.44
High MW PAH	NA			1,923.89
Low MW PAH	NA			2,351.55
Naphthalene	561		146.35	275.70
Methylnaphthalene, 2-		83		511.22
Methylnaphthalene, 1-	NA		152.81	348.35
biphenyl	NA		84.85	34.29
NAP d-Methyl	NA		17.57	241.63
naphthylene ace~	NA		24.53	2.85
naphthene ace~	NA			20.52
NAP t-Methyl	NA		78.95	178.52
Fluorine	536		22.98	34.93
Phenanthrene	1,170		271.05	459.33
Anthracene	845		29.03	35.99
PHH 1-Methyl	NA		167.30	208.22
Fluoranthene	2,230		490.50	211.98
Pyrene	1,520		387.92	206.31
Benz(a)Anthracene	1,050		150.88	146.34
Chrysene	1,290		197.13	182.27
Fluoranthene benzo(b)	NA		118.63	224.02
Fluoranthene benzo(k)	NA		67.36	133.69
pyrene benzo(e)	NA		92.87	206.43
Benzo-a-pyrene	1,450		105.85	204.01
perylene		NA	26.39	37.49
Indeno Pyrene (1,2,3-cd)	NA		73.61	114.25
Dibenzo Anthracene (a,h)	NA		18.52	57.33
perylene benzo (ghi)	NA		74.05	199.78

* All data is reported in ppb (µg/kg).
[1] sum PAH (Polycyclic Aromatic Hydrocarbons or Polynuclear Aromatic Hydrocarbons-PNAs) denotes sum of all 21 PAH compounds reported

Table C.2 VADEQ special study PCB and Pesticide sediment data in Straight Creek.

Date	PEC	08/13/97 6BSRA001.34	06/18/02 6BSRA001.11
Total PCB[1]	676	0.52	6.56
Total Chlorodane[2]	17.6	0.24	4.11
Sum DDE[3]	31.3		0.25
Sum DDD[4]	28		
Sum DDT[5]	62.9		1.04
Total DDT[6]	572		1.30
Total BDE[7]	NA	0.41	22.24
Hexachlorobenzene	NA		0.28
Heptachlor	NA		0.07
Heptachlor epoxide	16		0.07
Pentachloroanisole	NA		0.13
gamma BHC	4.99		
Total BHC	4.99		
Octachlorodibenzodioxin	NA		0.09
cpd-1[8]	NA		1.09

[*] All values reported in ppb (ug/kg)

[1] PCB Total PCB denotes sum of polychlorinated biphenyl congeners

[2] Total Total Chlordane denotes sum of chlordane and breakdown products

[3] DDE sum DDE denotes sum of dichlorodiphenyl dichloroethylene isomers

[4] DDD sum DDD denotes sum of dichlorodiphenyl dichloroethane isomers

[5] DDT sum DDT denotes sum of dichlorodiphenyl trichloroethane isomers

[6] Total DDT denotes sum of isomers of DDE, DDD, and DDT

[7] BDE Total BDE denotes sum of polybrominated diphenyl ether congeners

[8] cpd-1 denotes compound 1; Dichloromethyldiphenylether